Illuminating Engineering

TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

VOL. VII

JANUARY-DECEMBER

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Subject Index and Index to Authors

OFFICE OF THE GENERAL SECRETARY
29 WEST THIRTY-NINTH STREET
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SUBJECT INDEX.

*Pages following the numbers given should be consulted in referring to a topic or subject.

INDEX TO AUTHORS

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TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. JANUARY, 1912. NO. 1

COUNCIL NOTES.

The meeting of the council which was held in the general office, 29 West Thirty-ninth Street, New York, January 12, was devoted for the most part to the annual reports of committees. Such reports were received from the committee on lectures, the committee on papers, the committee on reciprocal relations with other societies, the committee on new membership, the committee on section development, the committee on advertising, the committee on reciprocal relations with opthalmological societies, and the committee on editing and publication. A vote of thanks was extended to each of these committees.

The annual report of the general secretary was received and, in accordance with a resolution passed, made to constitute the report of the council to the membership of the society. The report appears elsewhere in this number of the TRANSACTIONS.

A progress report was received from the committee on illumination primer.

A monthly report together with comments on the society's finances for the year 1911 was received from the finance committee. The final report of this committee is printed elsewhere in the present number of TRANSACTIONS.

Two amendments to the by-laws were read a second time and adopted. Accordingly Article III, section 3, now reads:

When applications for admission are received from persons residing within the territory of a section the general secretary shall notify the secretary of that section to make prompt report upon the application.

In connection with Article VII, section 12, of the constitution, this by-law has been added:

A revised report of any member's discussion on any paper must be received at the general office of the society within ten days after it has been mailed to the member, otherwise revision shall be made by the editing committee.

Twenty applicants for membership were elected. Eight resignations from membership were accepted. The name of one deceased member was dropped from the roll of membership.

At the conclusion of the meeting the following resolution was adopted:

Resolved that the council hereby express its hearty appreciation to retiring President A. E. Kennelly for the services which he rendered as president of the Illuminating Engineering Society.

Those present at the meeting were A. E. Kennelly, president: V. R. Lansingh, Louis Bell, George S. Barrows, H. E. Ives, L. B. Marks, E. B. Rosa, J. R. Cravath, A. S. McAllister and P. S. Millar, general secretary.

SECTION MEETINGS.

CHICAGO SECTION.

A meeting of the Chicago section was held in the Great Northern Hotel, January 18. Mr. C. S. Morgan read a paper entitled "Church and Auditorium Lighting."

The next meeting will be held February 22. Messrs. A. J. Sweet and L. C. Doane will present a paper entitled "Choice of Reflector; Its Influence on Illumination and Depression in Visual Function."

The tentative program of papers that has been announced for the succeeding meetings of the section is as follows:

March 21. A paper on office lighting will be read by Mr. S. E. Church of Sears, Roebuck & Co., Chicago.

April 18, "School Lighting." The name of author has not yet been announced.

May 16, "The Manufacture of Illuminating Glassware." The name of the author has not yet been announced.

NEW ENGLAND SECTION.

Three papers were read at the meeting of the New England section held January 22. One of the papers entitled "An Example of the Practical use of Tungsten Lamps to Produce Daylight" was presented by Dr. C. H. Sharp and Mr. Preston S. Millar. The other two papers dealing with the same subject

were presented by Dr. H. E. Ives and Mr. R. B. Hussey. These papers will appear in the February issue of the TRANSACTIONS.

For the February meeting of this section on the 26th, arrangements are being made to have Messrs. Arthur J. Sweet and L. C. Doane present a paper entitled "Choice of Reflector; Its Influence on Illumination Efficiency and Depression in Visual Function." The paper is the result of an extended investigation which has been conducted recently by the authors. It should occasion an unusual amount of interesting discussion. Two papers on certain aspects of street lighting also will probably be available.

NEW YORK SECTION.

The January meeting of the New York section on the 11th instant was devoted to a symposium on street lighting. The lighting of New York and other cities, both in this country and abroad was discussed in a general way. Informal talks were given by Messrs. H. Thurston Owens, George S. Barrows, O. L. Johnson and S. L. E. Rose. The subject was discussed by Dr. Louis Bell, Messrs. J. R. Cravath, Philander Betts, H. W. Hillman, W. T. Dempsey and others. About 150 members attended the meeting.

At the meeting which will be held February 8, Messrs. Arthur J. Sweet and L. C. Doane of the Holophane Company, Newark, O., will read a paper entitled "Choice of Reflector; Its Influence on Illumination Efficiency and Depression in Visual Function." The paper will be an embodiment of the results and conclusions derived from an extensive investigation recently completed by the authors.

Dr. Herbert E. Ives will present a paper on "The Application of Photography to Photometric Problems" at the March Meeting on the 14th. At this meeting there will also be a kinetographic exhibition by the Kinemacolor Company in conjunction with a second paper on the the relation of light to photography.

For the meeting on April 18, there will be two papers: one on "Ship Lighting"; and the other on the lighting of coal mines. The names of the authors of these two papers have not been announced.

PHILADELPHIA SECTION.

Probably the largest meeting, in point of attendance, ever held by a section of the society was that of the Philadelphia section on January 19. Two hundred and forty-four members and guests were present. Mr. V. R. Lansingh, the society's newly-elected president, gave an interesting lecture on "The Architect and the Illuminating Engineer." Mr. L. B. Marks, the first president of the society, gave an instructive talk on "The Illumination of Interiors by Daylight and by Artificial Light." Considerable interest, too, was manifested in the first of a series of short talks on the essential principles of illumination, which will be given before the meetings of the present season by Prof. Arthur J. Rowland, director of the School of Engineering of Drexel Institute, Philadelphia. In conjunction with the meeting there was also an exhibition of gas meters and a kinetographic exhibition of "the house electrical." An informal dinner preceded the meeting.

At the meeting to be held February 16, Prof. George A. Hoadley, professor of physics at Swarthmore College, will deliver a lecture on "The Physics of Light." Prof. Hoadley will supplement his lecture with a series of experiments and stereopticon views. During the meeting there will be on exhibition, an assortment of electric lighting units.

For the March meeting there will be a paper entitled "The Application of Photography to Photometric Problems" by Dr. H. F. Ives and a lecture on European lighting conditions by Dr. C H. Sharp.

ANNUAL MEETING.

The annual meeting of the society was held in the Machinery Club, New York, January 12. Eighty-nine members and guests were present. After an informal dinner brief addresses were made by the retiring and incoming presidents of the society, and by representatives of other professional societies. During the course of the meeting, retiring President A. E. Kennelly announced the results of the annual election. Mr. V. R. Lan-

singh was declared elected president, Mr. Norman Macbeth, vice-president; Mr. Wm. J. Serrill, treasurer; and Mr. Preston S. Millar, general secretary. Messrs. R. C. Ware, Albert J. Marshall and C. J. Russell were elected directors. These announcements were greeted with a round of loud applause.

Dr. Kennelly in his address dwelt upon the province of the illuminating engineer and the works which remains for the society to perform. Within the purview of the illuminating engineer, said Dr. Kennelly, are problems both innumerable and diverse, upon the solution of which depends his ultimate achievement. Whether he fancy the faint luminescence of the firefly or contemplate the copious effulgence of the most brilliant flame arc lamp; whether he philosophize on the psychological and physiological effects of light, or whether he devote himself to the purely commercial aspects of illuminating engineering, all his endeavors and all the knowledge he may acquire must be contributory to a final but mighty achievement—perfection in the application of light.

As regards the society, Dr. Kennelly said there were two notable functions which it should logically perform. In the first instance, of course, it should advance the theory and practice of illuminating engineering. Secondly, it should eventually become a clearing house for information pertaining to the art and science of illumination.

Mr. Gano Dunn, president of the American Institute of Electrical Engineers, in his address said that the electrical engineering profession did not at the time of the inception of the society realize the scope of illuminating engineering. Some of its members, he intimated, regarded the innovation slightly; others were either quizzical or mildly indifferent. Only a few received it with enthusiasm. These different attitudes toward illuminating engineering Mr. Dunn attributed to the tremendous development in many directions which electrical engineering was undergoing at the time. Ten years of marvelous progress in the lighting industry, however, Mr. Dunn continued, has convinced even the most skeptical of electrical engineers that illuminating engineering is not a superficial accession to the field of professional endeavor. To-day the illuminating engineer is regarded as the peer

of the electrical engineer. That this change was in no small measure due to the concerted action of members of the Illuminating Engineering Society, Mr. Dunn stated implicitly.

Concluding his remarks, Mr. Dunn said he had been delegated by the board of directors of the American Institute of Electrical Engineers to convey to the Illuminating Engineering Society an expression of their good will and a desire to cooperate heartily in any mutually advantageous work.

Hon. I. C. Copley, president of the American Gas Institute, presented a brief but interesting retrospect of the influence that modern illuminants had exerted upon the gas industry. Thirty-five years ago, the beginning of what has been a period of phenomenal progress in the lighting industry of this country, Mr. Copley related, there was considerable apprehension among the gas interests. The future of the gas industry was frequently spoken of as gloomy; the prospects were certainly not inspiriting. Indeed, such an uncanny outlook was truly reflected in the market quotations on gas stocks. This state of affairs became even more evidently critical the day after the invention of the incandescent lamp was announced by Edison. Gas stocks immediately took a sharp decline in the market. For a time afterward the prevailing conditions as regards the gas industry were little short of demoralizing. But nothing serious happened after all; dire suspicions and evil prognostications proved to be unfounded. Conditions that at first seemingly presaged disaster really betokened a boom more auspicious than the most expectant optimist should have dared to prophecy. Subsequently the Welsbach mantle, the metal filament and the vapor lamps were introduced. Still later came many improvements in practically every form of illuminant. The significant outcome of this whole period of phenomenal progress and development, however, Mr. Copley concluded, has been that all the well-managed gas companies in the United States to-day are selling from four to ten times as much gas per capita as they were selling as late as twenty-five years since. This increase in the consumption of gas of course does not represent an increase in the consumption of gas for lighting purposes alone; rather it indicates a remarkable progress which

has been occasioned to a large extent by the development of several lighting units.

Dr. Alexander C. Humphreys, president of the Stevens Institute of Technology, also president of the American Society of Mechnical Engineers, alluded particularly to the advantages that ensue from cooperation between professional or scientific societies. Cooperation, if it does nothing else, said Dr. Humphreys, eliminates much of the needless and costly work which occurs when societies having common interests work independently. In the case of the cooperative relations pending between the representative committees of the American Society of Mechanical Engineers and the Illuminating Engineering Society he felt sure that whatever work may be undertaken by the commit tees should prove mutually advantageous to both societies.

Mr. Walter Cook, president of the American Institute of Architects, confined his remarks to the work of the architect. His work, Mr. Cook stated, is variegated and encompassing. For this very reason the architect must needs interest himself in some of the phases of illuminating engineering, particularly the art of illumination.

Prof. C. A. Martin, director of the School of Architecture of Cornell University, also referred to the architect and his profession. Beauty, according to Prof. Martin, is the object sought by the architect in all his constructive work. Of course, Prof. Martin added, the architect must recognize many of the more imperative requirements of engineering efficiency; but ostensibly he aims to cultivate the beautiful no matter whether he is concerned with a problem in lighting or with the erection of some gigantic building.

The importance of good lighting in steel mills was emphasized by Mr. R. B. Shover, president of the American Association of Iron and Steel Electrical Engineers. Within the past year and a half, Mr. Shover said, mill owners had given the problem of lighting their mills properly much serious consideration. They had begun to realize that this detail of their industry which had been so long treated slightly, is a potent factor in promoting efficiency in production and in preventing innumerable accidents in mills. About a year ago the problem was first mooted before a

meeting of the organization which he represented. A committee was immediately appointed to take up the question. Meantime it was planned to devote a whole session of the next convention of the association to the subject.

Dr. William H. Tolman, secretary of the American Museum of Safety, outlined in an interesting manner the work which the museum is doing toward the prevention of accidents not only in manufacturing establishments but in the street and in the home. Dr. Tolman urged the society to collect for exhibition in the museum of safety lighting devices, charts and other exhibits which might assist in some way the safeguarding of humanity from accidents and losses of life and property.

In his inaugural address President-elect V. R. Lansingh spoke of the unique position among professional societies occupied by the Illuminating Engineering Society. He indicated in a general way the lines of progress which the society might pursue during the near future. For the present, he emphasized, the work of the society must be primarily of an educational character. Mr. Lansingh's address "Some Thoughts on the Society's Development" appears in this issue of the TRANSACTIONS.

At the conclusion of the meeting Dr. Kennelly read an abstract of the annual report of the council to the society. The report, which is the annual report of the general secretary, is printed in toto elsewhere in this number of the TRANSACTIONS.

GENERAL SECRETARY'S REPORT TO COUNCIL FOR THE YEAR 1911.

The year of 1911 has witnessed a quiet, persistent movement along lines laid down in previous years, and the inception of a number of new enterprises which are as yet in an embryonic or at most an inchoate state. It has been a year of evolution. In material things the society has held its own. In technical knowledge, appreciation of best ways and means of promoting the cause of good illumination through the society's efforts, and in the formulation and application of plans for accomplishing this end, notable advances have been made. Amplification of these statements appears in the following review.

TRANSACTIONS.

In volume the TRANSACTIONS are growing from year to year as is indicated.

Volume No.	Total pages	No. of papers	Pages dvoted to papers
I	424	16	163
II	834	44	468
III	786	40	461
IV	997	50	592
V	902	43	638
VI	1,024	41	716
	4,967	234	3,038

As compared with the five earlier volumes of the TRANSACTIONS, the 1911 volume differs but little as to the nature of subjects discussed. Such differences as may be noted do not appear to indicate any change in trend of thought, but are due rather to the fact that among so small a number of papers (41) distributed over such a broad range of subjects, a representative distribution cannot be anticipated.

Queries such as the following are frequently heard. "What is an illuminating engineer?" "What is illuminating engineering?" "For what does the Illuminating Engineering Society stand?" It has been suggested that the lectures presented in 1910 under the joint auspices of this society and the Johns Hopkins University afford an answer to such questions. These lectures were arranged after much intelligent deliberation directed toward securing a proper balance among the subjects dealt with and can therefore be considered with propriety as delineating the scope and character of the profession of illuminating engineering as well as the purpose which this society seeks to serve. It would appear to be in order to draw attention to the fact that in the six volumes of the TRANSACTIONS of this society a further answer to these questions may be found. The nature of the discussions included has been determined undoubtedly by the trend of thought and work among the membership, and by the views of the members, numbering perhaps 40, upon whom the responsibility for the papers programs has devolved during the six years. Instead of a deliberately planned distribution among the various subjects, that obtaining in the TRANSACTIONS

is the natural result of the development of the art in the course of the professional or industrial work of the members of the society at large. To facilitate consideration of this feature of the TRANSACTIONS, an analysis of the 234 papers has been made. The classification adopted has been brought into conformity with that of the lecture course in order to permit of a comparison between the lectures and the TRANSACTIONS papers, with respect to distribution among the subjects treated. No other practicable means being available, the basis has been made the number of pages devoted to each subject. This classification has not proven altogether satisfactory and has necessitated a number of arbitrary assignments of questionable validity, but on the whole the result should serve the present purpose.

DISTRIBUTION OF PAPERS AMONG SUBJECTS.

	Lecture course		Six volumes of TRANSACTIONS	
	No. of pages	Per cent.	No. of pages	Per cent.
Physical Basis of Light Production	24	2.3	119	3.9
Physical Characteristics of Sources	66	6.4	159	5.2
Chemistry of Light Production	16	1.6	0	0.0
Electric Illuminants	48	4.7	171	5.6
Gas and Oil Illuminants	53	5.1	70	2.3
Incandescent Gas Mantle Lamps	25	2.4	122	4.0
Electric and Gas Lighting (General Manufacture and Distribution)	150	14.5	11	0.4
Units, Standards and Terminology	24	2.3	237	7.8
Photometry	96	9.3	159	5.2
Architecture	18	1.7	71	2.3
Physiology and Psychology	80	7.8	197	6.5
Calculations	42	4.1	249	8.2
Interior Illumination	147	14.3	809	26.7
Exterior Illumination	89	8.6	172	5.7
Reflectors, Glassware, Etc.	45	4.4	195	6.4
Fixtures	14	1.4	105	3.5
Commercial Aspects of Electric and Gas Lighting	94	9.1	44	1.4
The Illuminating Engineering Society	0	0.0	30	1.0
Illuminating Engineering	0	0.0	44	1.4
Miscellaneous	—	—	74	2.5
Totals	1,031		3,038	

The course of lectures affords an excellent indication of the scope of the society's endeavors. The TRANSACTIONS, while

inferior in respect to logical arrangement and completeness, serve this purpose even better. With the two available, there can remain no doubt as to the society's purposes and policy. Not only in profession but also in achievement it seeks to promote the advancement of good illumination. Its TRANSACTIONS, as well as the privilege of its floor, are available to all who seek in a suitable manner to contribute toward this end through the discussion of subjects pertaining to the science and practise of illuminating engineering.

SECTION ACTIVITIES.

No new sections were established during this year, although, as a result of local demand, consideration was given to a project to form a Baltimore-Washington section. A committee of local members and society officers investigated the situation and reported adversely.

The activities of the four sections are summed up in the following table:

	Chicago	New England	New York	Philadelphia	Totals
Technical meetings	9	6	9	9	33
Papers contributed to TRANSACTIONS	2	3[1]	12[1]	6[2]	22
Papers not reproduced in TRANSACTIONS	5	5	1	6	17
Meetings given over to discussion	2	0	2	0	4

The much mooted question of most desirable subjects for discussion at section meetings has received considerable attention throughout the year without developing unanimity of opinion. The section boards of managers have continued as in the past to arrange for the presentation of such suitable subjects as might be available. There appears, however, to have been little tendency to arrange for papers which review the elementary

[1] One paper presented at both meetings.

[2] Printing of one paper not assured.

aspects of the fundamentals of the subject of illuminating engineering, which matters are now fairly well set forth in the TRANSACTIONS and the lecture course reprints. There is room to question if opportunities are not being neglected by failure to have presented in a more or less popular way the scientific researches which are reported from time to time in the transactions of our own and other societies, and in the technical press. This is a field of enterprise to which attention has previously been directed and which section boards would do well to consider.

As during previous years, the sections in Boston and Philadelphia have enjoyed the privilege of holding technical meetings in the auditoriums of the local lighting companies, favors which the society is glad to acknowledge with appreciation. In New York the section meetings are held in a rented auditorium at the expense of the society, and this is done not so much because it is not feasible to avoid this expense as because the council and the New York section board of managers deem it a wise policy to hold the meetings in the United Engineering Societies Building.

It is provided in the by-laws that meetings of sections shall be held monthly, except during July, August and September. The wisdom of this provision is being questioned. Many members of the society feel that if in any month there is available neither paper nor lecture which is of enough interest and importance to afford a notable contribution or to call forth a constructive discussion, it would be the part of wisdom to vary from the rule and hold no meeting until such paper or lecture can be obtained. The board of managers of the New England section has taken this stand and there would seem to be enough opinion in support of it to make it desirable to modify the by-law and to extend to the boards of managers larger discretionary powers in these matters.

MEMBERSHIP.

The membership at the end of 1910 was 1,530. At that time the resignations of 68 members became effective, making the

membership at the beginning of 1911, 1,462. The changes which have taken place during the year are as follows:

Membership at beginning of year		1,462
Additions		180
Elected to membership during year	173	
Reinstated	7	
Defections		224
Resigned	127	
Dropped for non-payment of dues	91	
Deceased	6	
Membership Dec. 31, 1911		1,418

In considering these changes it must be remembered that as the result of a membership campaign, somewhat more than 500 new members were added in the summer and autumn of 1910. Apparently a number of these joined the society under somewhat of a misconception as to its functions and found by trial too little of immediate interest to them in the society's work to warrant continuance of the membership. It is probably not surprising that the majority of the defections recorded are from among these recently affiliated members.

The accessions to the membership appear to be a fair evidence of the gradual growth of the society's influence, since they were added month by month through the year and were in no way due to any membership campaign.

Six members have been lost through death:

N. A. Dutton
Dr. Henry Gradle
L. R. Hopton
B. G. McNabb
R. W. Morgan
E. F. Phillips

There is no notable change in the distribution of the membership among the industries and professions represented. The distribution as shown in the accompanying table is substantially that shown in the annual report for 1910.

DISTRIBUTION OF MEMBERSHIP AMONG THE PROFESSIONS AND INDUSTRIES REPRESENTED.*

Class	Total	Per cent.
Architects	14	1.0
Decorators	2	0.1
Fixed manufacturers	8	0.5
Contractors and Jobbers	71	4.9
Pedagogues	71	4.9
Ophthalmologists	10	0.7
Testing and Research	25	1.7
Consulting Illuminating Engineers	5	0.3
Illuminating Engineers associated with manufacturing organizations	8	0.5
Illuminating Engineers associated with lighting companies	8	0.5
Electric lighting	314	21.6
Gas lighting	231	15.9
Electric and gas lighting	52	3.6
Electric lamp manufacturers	201	13.9
Gas lamp manufacturers	39	2.7
Manufacturers of glassware	140	10.0
Consulting engineers, electric	59	4.0
" " gas	6	0.4
Electric lighting other than public	78	5.4
Technical journals	18	1.2
Municipal and Public Service Commission Engineers	21	1.4
Miscellaneous illuminating	9	0.6
Scattering	9	0.6
Unclassified	52	3.6
	1,451	100.0

*Membership as of middle of December, 1911.

FINANCES.

The committee on finance has repeatedly drawn attention to the inadequacy of membership dues to defray the legitimate and necessary expenses of the society. As the membership has increased, the income from dues has increased proportionally and the expenses of operating the society have increased. The proportional inadequacy of the dues has not been improved in the process, so that the gap between income per member and dues per member remains of the same order, but aggregates a larger sum. The surplus of earlier years has not been added to in recent years. Indeed it has only been by the exercise of

marked economy and the utilization of income from advertising that a material deficit has been avoided.

Already the hampering influence of financial stringency has been felt. A prospectus which the council has ordered prepared in order to set forth the society's purposes and work, has not yet been printed. A pamphlet for prospective authors, calculated to assist in the standardization of our TRANSACTIONS and in a better understanding with members concerning the requirements of the committees on papers and editing and publication, has also been delayed.

The 1911 administration has felt keenly the importance of the financial problem thus confronting the society. The committee on finance has taken the position that the legitimate expenses of the society ought to be defrayed by means of the income from membership dues, and that the further healthy growth of the society is in part contingent upon such condition. In this view it has had the support of the majority of the council. After considering the question in its various ramifications, a proposition that the membership dues be advanced to $7.50 in 1913 was formulated. Upon submission to representatives of the sections at the meeting held under the auspices of the section development committee during the term of the Chicago convention this proposal met with such adverse comment that it was withdrawn. At the time, the suggestion was made that in larger membership increases a remedy for the situation might be found.

In order to test the correctness of this view, a statement has been prepared in which are set forth the probable expenses of conducting the society along lines without any provision for extension of research and educational work, and with various assumptions as to increase in membership during the next three years. Naturally, such figures are nothing more than speculations, but assuming that they are founded upon sound premises, they are strongly indicative of the conclusion that under no conditions which are likely to prevail during the next three years can membership dues of $5.00 prove adequate to meeting the ordinary expenses of the society.

Advertising in the past has made up any deficiencies which developed. The income from advertising, however, has not

increased. In consequence, a proportional deficiency would no longer be met in the same way, but would leave a deficit unprovided for in any way. To deal rightly with this financial question would appear to be the most important problem which the society faces at this time.

COMMITTEES.

Standing Committees Created by the Constitution. Committee on Finance.—As during preceding years this committee has passed upon all disbursements by the society and has advised the council in all matters of finance. There have been monthly meetings of the committee preceding the council meetings and a report from the committee has been submitted at each meeting of the council.

Committee on Papers.—This committee has approved all papers which have been printed in the TRANSACTIONS and has had the responsibility of arranging the papers program for the annual convention. The committee has found it necessary to vary somewhat from tradition in order to meet the views of its members concerning the requirements of the society, and in particular has measurably lessened the rigidity of the society's stand against so-called commercialism in discussions.

Committee on Editing and Publication.—For the first time in the history of the society, the committee has not been required to do the actual work of editing papers and discussions, and of supervising the printing of the TRANSACTIONS. All such work has been assumed by the assistant secretary as a part of the work of the general office. The functions of the committee have consisted in exercising a measure of supervision over the editorial policy and in advising the assistant secretary upon matters which he submitted to them.

STANDING COMMITTEES CREATED BY THE COUNCIL.

Committee on Nomenclature and Standards.—Under the supervision of this committee the sub-committee on photometric units has proceeded with the work of standardizing units, symbols and terminology, attempting under the mandate of the 1910 Baltimore convention to promote international cooperative consid-

eration and action. The report of the committee presented at the Chicago convention, included chiefly a record of the work of the sub-committee, and in particular embodied a recommendation "that negotiations with individuals and societies in other lands be carried on with a view to the possibility that eventually this society would arrange for an international conference to bring about an agreement on these subjects." This recommendation was favorably considered by the council at its November meeting and the committee was authorized to begin negotiations along the lines indicated. Accordingly the secretary of the committee has addressed a communication to various engineering and scientific bodies abroad and at home, suggesting tentatively that a conference be arranged and requesting an expression of views. It is too early to forecast the results of this activity of the committee.

Committee on Advertising.—The amount of advertising published in the TRANSACTIONS has varied but little during the past few years. At the beginning of 1911 the committee requested direction from the council as to the desirability of endeavoring to increase this amount of advertising. The council resolved that for the time at least, such effort was not desirable. During the latter part of the year this matter was reconsidered and the committee has now been instructed that double the previous number of pages would be available for advertising, and has been asked to endeavor to obtain a corresponding increase in the advertising.

Committee on New Membership.—The request of the committee to the council for instructions resulted in a resolution that a vigorous new membership campaign during 1911 was not considered desirable. The committee was directed rather to endeavor to promote a wholesome, gradual growth in membership through efforts to bring together the society and those who either need the society or could serve it. The efforts of the committee have been confined to work of a general character along these lines, with the exception of a membership suggestion and application blank which were included with the announcements of the annual convention sent to a large number of representatives of public lighting organizations throughout the country.

Committee on Section Development.—This committee, being composed of officers of the various sections, has found it difficult to hold frequent meetings. The first meeting after organization was held in March and resulted in submission to the council of a report suggesting the extension of section and society work, which report is reflected in a number of the new developments of the year. During the term of the annual convention a public meeting was held under the auspices of the committee for the general discussion of section and society problems. A third meeting has been held, January 12. In addition to discussing various matters pertaining to section work an outline of section management was prepared for the guidance of present and future boards of managers. This contained such procedure as met the approval of the section officers present, and is intended to form with the constitution and by-laws a fairly complete guide.

Committee on Progress.—This committee presented a report at the annual convention, thereby fulfilling the purpose which it was created to serve.

Committee on Reciprocal Relations with Other Societies.—This committee, appointed during the latter part of the year, has organized and mapped out a campaign which is already in course of prosecution. Its efforts bid fair to arouse no small amount of interest on the part of engineering and technical societies or associations and should be instrumental in largely extending the influence of our society.

Committee on Cooperative Relations with Ophthalmological Organizations.—This committee was intended to serve in a specific case the same purpose which the committee on reciprocal relations with other societies was in a later appointment intended to serve in a general way. The two committees have an understanding as to methods of procedure and may be expected either to parallel one another's activities or to be merged into one committee.

Committee on Research.—The committee, the appointment of which was authorized by the council two years ago, has at last been appointed and should find it possible to organize during the coming year.

TEMPORARY COMMITTEES CREATED BY THE COUNCIL.

Committee on Lectures.—This committee was reappointed largely as a formality in order to permit the rendering of a final report covering the completion of matters of detail involved in the 1910 lecture course at the Johns Hopkins University. This responsibility having been discharged, there remains no further work for the committee to do.

Committee on Policy.—The rather numerous recommendations submitted to the council by the committee on section development required more extended consideration than the council at large could give them. Accordingly the committee on policy, consisting of the present executive committee and the past presidents of the society was appointed to consider and report upon the subjects under discussion. The committee rendered a prompt report and was discharged.

Committee on Illumination Primer.—To the committee on illumination primer was assigned the important task of drawing up for general dissemination a treatise dealing with those elementary principles of illumination, to which more attention should be paid by the public at large. The committee is now engaged on this work and is expected to report during 1912.

ANNUAL CONVENTION.

At the fifth annual convention held in Chicago, sessions were for the first time extended through four days. All meetings were well attended and most were marked by spirited discussion. Technical and entertainment features were well planned and executed. The society is indebted to the officers and members of the Chicago section for maintaining and even advancing the high standard set in previous conventions.

GENERAL OFFICE.

The society's general office, located in the United Engineering Societies Building, consists of one room 12 x 24 in which the assistant secretary and a stenographer are located, and council and committee meetings are held; and a storeroom 8 x 8 in which copies of the TRANSACTIONS and stationery are stored. The annual rental of these two rooms is $460. These facilities have proven inadequate, and even with the present membership should

be augmented. With such growth in membership as may be anticipated, an increase in office space will soon become imperative.

In the beginning, but little beyond perfunctory office duties were performed by the assistant secretary. More recently, however, the tendency has been, rightly, to concentrate much of the work in the general office. During the past year all editing and publication work has been done by the assistant secretary. The accounting work of the advertising committee has also been transferred to the general office. Also the handling of section discussions in part has been transferred from section secretaries to the general office. These new duties make greater demands upon the capability and activity of the assistant secretary, rendering his office of greater importance. It is a pleasure to testify to the satisfactory manner in which upon the whole the responsibilities have been met.

SUMMARY.

In the foregoing review, inadequacy of financial resources stands out as the only fundamental weakness. It is apparent that the society must address itself to the solution of this problem forthwith, if enterprises already undertaken are to be carried to a successful consummation, and probable demands of the near future are to be met.

Much of the work of the society has been done gratuitously by members prominently identified with its history. In a sense this has been fortunate because it is doubtful if like service could have been commanded at any rate of remuneration within reach of such a society. Further it is doubtful if equally efficient efforts put forth by salaried officers would have been as effective. But the time has come when the society's affairs demand a larger amount of effort than can in fairness be asked of members who, however willing, must serve at the expense of their other interests; and to substitute salaried officers for members serving gratuitously is an expensive proceeding.

The society must grow in influence. This involves extension of activities and scope. There is much educational work to be done. Research must be carried on if the boundaries of our knowledge are to be extended. The society should assume a fair share of this burden.

All these things require funds which under existing conditions of organization are not in sight. The total income is barely adequate to meet routine expenses, and unless increased may prove inadequate in the near future.

This financial handicap once overcome, there is every reason to anticipate continued growth in influence and usefulness. An organization of proven merit; a council composed of men devoted to the society's interests and qualified to guard its welfare; strong, active committees; a membership among which there is a large proportion of men ready and willing to perform any reasonable service for the promotion of the art; a cause whose growing importance is just beginning to gain universal recognition; these and other conditions are favorable to an increase in effectiveness which shall form a fitting continuation of the creditable record already made by the Illuminating Engineering Society.

ANNUAL REPORT OF THE FINANCE COMMITTEE FOR THE FISCAL YEAR 1911.

To the Council of the Illuminating Engineering Society:

In accordance with the provisions of the constitution of the society, the finance committee has during the past year exercised direct supervision over the financial affairs of the society.

The committee held monthly meetings except during the summer, made recommendations to the council on all matters submitted for examination and report, and examined and approved all bills paid by the society.

The financial condition of the society as of Dec. 31, 1911, is shown in the subjoined statement of Messrs. Peirce, Struss & Co., certified public accountants, who were employed by authorization of the council to audit the books and accounts of the society.

Although the statement of the auditors shows earnings amounting to $481.95 in excess of expenses for the year, the audit takes no cognizance of those expenses incurred during 1911 for which bills were not received during the year. The committee wishes to point out that the statement of net earnings must be taken with this limitation.

The figures for the year show that the society is still de-

pendent to a considerable extent for its financial support upon the income derived from advertisements in the TRANSACTIONS, and that without this income the society would face a deficit.

From past experience and from careful estimates of future expenses there does not appear to be any escape from the conclusion that even with largely increased membership the present annual dues of $5.00 and initiation fee of $2.50 will alone be sufficient to render the society self-supporting.

Respectfully submitted,
A. A. POPE,
A. S. MCALLISTER,
L. B. MARKS, *Chairman.*

EXHIBIT NO. 1.—BALANCE SHEET—DECEMBER 31, 1911.

ASSETS.

Cash:		
In bank	$720.55	
In drawer	100.00	
Total		$ 820.55
Accounts receivable:		
Members dues—1911	65.00	
Due for advertising—1910	6.68	
Due for advertising—1911	568.42	
Initiation fees	50.00	
Sundry charges to members	59.85	
Total		549.95
Property Accounts:		
Furniture and fixtures	501.16	
Less depreciation	100.23	
Net	400.93	
Badges on hand (28)	70.00	
Total		470.93
Investments:		
Northern Pacific Railway and Great Northern Railway bonds, $2,000		1,920.00
Total		$3,761.43

LIABILITIES.

Accounts payable	$742.06	
Dues paid in advance	129.80	
Total		871.86

SURPLUS.

Undivided profits (Exhibit No. 3)		2,889.57
		$3,761.43

EXHIBIT NO. 2.—STATEMENT OF INCOME AND EXPENSES FOR THE YEAR ENDED DECEMBER 31, 1911.

INCOME.

Members dues	$7,152.50	
Advertising	1,225.80	
Miscellaneous sales of TRANSACTIONS	231.01	
Profit on badges sold	23.00	
Members certificates	12.00	
Initiation fees	175.00	
Interest on bonds	80.00	
Miscellaneous	4.44	
Total		$8,903.75

EXPENSES.

TRANSACTIONS	3,588.30	
Membership committee	44.57	
Convention expense	275.65	
Election expense 1911 (part)	59.15	
Committee on Nomenclature and Standards	3.00	
General Office (Schedule No. 3)	3,211.79	
Treasurer's expense	20.00	
Exchange of checks	7.65	
Depreciation of furniture and fixtures (20%)	100.23	
Chicago section	323.82	
New York section	481.73	
New England section	160.59	
Philadelphia section	145.32	
Total		8,421.80
Earnings for the year		$ 481.95

EXHIBIT NO. 3.—SURPLUS ACCOUNT DECEMBER 31, 1911.

Surplus—January 1, 1911		$2,873.46
Back dues—1908		5.00
Earnings for year 1911		481.95
Total		$3,360.41
Bad and doubtful accounts on the books for several years prior to January 1, 1911	$340.69	
Art exhibit—1909	108.65	
Election expense—1910	21.50	
Total		470.48
		$2,689.57

SCHEDULE NO. 3.—ANALYSIS OF GENERAL OFFICE ACCOUNT FOR THE TWELVE MONTHS ENDED DECEMBER 31, 1911.

Salary of assistant secretary	$1,304.25
Stenographers salary	516.05
Postage	314.59
Telegraph and telephone	106.41
Rent of office	396.00
Rent of storage vault	64.00
Auditors fees	75.00
Printing and stationery	285.37
Incidentals	150.12
Total	$3,211.79

NOTICE.

The illumination primer which is being compiled by a committee composed of Mr. L. B. Marks, chairman; Dr. Louis Bell and Mr. J. R. Cravath, will be written in a distinctly popular form. It is intended for the reading of those who have little or no knowledge of either illumination or illuminating engineering. The present indications are that a very large edition of the primer will be published. It is likely also that it will be eventually printed in several languages.

ERRATUM.

On page 633, volume VI, No. 7 (October, 1911, issue of the TRANSACTIONS)

60-watt lamp .... 1.15 in.

near the bottom of the page should read,

60-watt lamp .... 0.15 in.

SOME THOUGHTS ON THE SOCIETY'S DEVELOPMENT.*

In the presidential address by Doctor Hyde at the time of the Johns Hopkins University lecture course, he outlined the ideals and aims of the Illuminating Engineering Society. I wish to present for your consideration a few concrete suggestions looking forward in the direction of the ideals so well outlined by Dr. Hyde. In an effort to attain these ideals we must approach them step by step, and this evening I present for your consideration one or two suggestions looking toward the future progress of the society.

The Illuminating Engineering Society occupies a unique posi- among technical bodies, inasmuch as the work which it aims to accomplish brings it in direct contact with, and makes it of interest to, not only the engineer and those specially interested in lighting, but to practically everybody in the civilized world. The work of most technical societies is peculiarly their own and the public is but little interested in anything but the results accomplished and is not called upon to take any active interest in them. Thus in the case of the electrical engineer—while a large majority of the people enjoy the benefits of his knowledge and art, but few are called upon to take any active interest in the means by which he accomplishes his results: nor are they called upon to put into practise the principles of electrical engineering. In the field of illumination, however, the subject is of interest to everyone and there are few people in the country who cannot change the results of their illumination, often by simple means. Even the farmer, with his oil lamps, can often improve his illumination by making simple changes in the location or shading of his lamps. The subject of illumination, therefore, is one of universal interest.

Until the last few years the subject has been given but little study or thought, with the result that most of lighting now installed is very often poorly done, not only from the standpoint of economy but also from that of the effect on the eye and the artistic results obtained. This also applies to even the

* Presidential address of V. R. Lansingh at the annual meeting of the Illuminating Engineering Society, January 12, 1912.

majority of present day installations, especially of the smaller type, although it is to be noted that a large number of them are based on modern lighting ideas. It is only necessary, however, to walk down any of our great avenues of trade in this or practically any other large city and see the glaring examples of bad lighting and poor illumination to realize that as yet the principles of good illumination have not penetrated deeply into the minds of the great public. The work of this society has been to aid in the development of the knowledge as well as the art of illumination and it is or should be one of the primary functions of the society to spread this knowledge as far as possible and to become a predominant educational factor in the country, as far as it relates to good illumination. Education must therefore play a more important part in the work of this society than in probably any other technical body.

Up to the present time very few people have even heard the term "illuminating engineering," and of those who have, most have an extremely vague idea of what it means. What then can the society do to promote a knowledge of what constitutes good illumination so that it may lead to the improvement of modern lighting methods, not only in the cases which come directly under the professional illuminating engineer, but also in the great majority of lighting installations. This, then, is one of the problems which the society must solve if it is to fulfil its proper scope. There are many ways in which the problem can be attacked. Some of these may be briefly stated as follows:

Enlargement of membership and sections of the society.

Increasing its membership among those who are not primarily interested in "illuminating engineering," using the term in its narrow sense.

Cooperation with other technical societies along work which we have in common.

The establishment of courses in illumination in the different technical schools and colleges of the country and the enlargement of such courses where they already exist.

The publication of articles on illumination not only in technical journals devoted to the subject of light directly or indirectly,

but also in those technical journals primarily devoted to other purposes. Thus, articles on illumination have been appearing recently in such journals as architectural papers, textile papers, business management papers, etc.

The publication of articles on good illumination in newspapers, magazines, etc., which reach the general public.

The publication of books, pamphlets, primers, etc. on illumination which are intended not only for the technically trained man, but also for the ordinary citizen. These, among others, will suggest themselves as methods by which the society can fulfil its true function in the education of the public along these lines.

Much has already been done in these directions. Thus the committee on reciprocal relations with other societies has started in its work and this promises to be of great benefit, not only to this society but also to other societies with which we have more or less in common; it will also prevent the overlapping and duplication of work, and will enable the society, as the committee has stated, "to become the clearing house for all societies on the subject of illumination."

The committee on an illumination primer has also started work and this promises perhaps to be of more direct educational benefit to the public at large than any work so far accomplished by this society. We must not, however, limit our educational work to the lines which are here suggested and it is to be hoped that as time goes on the society will be in a position to undertake more and more educational work, thus greatly enlarging its field of influence and usefulness. All this good work in turn reacts upon the society and with the added increase in the knowledge of good illumination and an awakened public sentiment, the society can find its growth and inspiration.

The term "engineer" is perhaps in some ways a misnomer, as so many of the sides of the subject are not really engineering in their nature, but quite different. Naturally the engineering side of this subject was the first to be seriously considered and hence the term "illuminating engineering" was adopted and made to include many aspects of the subject which are not in themselves of an engineering nature, such as the physiological, psychological and esthetic aspects. In fact the inclusiveness of the work of

the illuminating engineer has been recognized as being so diversified that suggestions have been made for changing the name of the society to something which will more adequately express the aims and scope of the work to be done.

The society in order to do its best work should be a well balanced organization. Despite its name the society is not in many respects an engineering society, nor will it be as long as we deal with light not only from a physical standpoint but also from one of hygiene of the eye and decoration. In the analysis as presented in the council's report of the distribution of subjects covered by both the Johns Hopkins University lecture course and the six volumes of the TRANSACTIONS we find that this balance in the society, which is so much desired, is more or less lacking. Thus in the case of fixtures, which play an important part in most lighting installations and on which many times either the success or failure of the installation will depend, we have only 1.4 per cent. of the Johns Hopkins University lecture course, and 3.5 per cent. of the TRANSACTIONS devoted to this subject. The classification of members according to occupation further emphasizes this. In its new membership work, therefore, it is to be hoped that the society may so shape its course as to bring in not only new members who are interested in illuminating engineering as used in its narrower sense, but also those who are interested in the co-ordinate branches of illuminating engineering used in its broader sense.

By following out these different lines of educational work and by increasing its membership and usefulness in those allied fields which relate only indirectly to the field of illuminating engineering the society may do much not only to justify its existence but also increase both in members and usefulness.

INSTITUTIONAL LIGHTING, WITH SPECIAL REFERENCE TO HOSPITALS.*

BY W. M. L. COPLIN, M. D.

During the last few years I have been especially interested in problems of institutional organization, construction and equipment; among the many factors involved proper lighting is clearly of paramount importance. It is unnecessary to say that if daylight could be controlled so as to insure its delivery on all occasions and at all times artificial lighting would not be needed; but natural light cannot be depended upon for much of the illumination necessary in the various departments of institutions. This is true not only of hospitals, but of nearly all institutions similar in kind, although accomplishing entirely different ends. Colleges and laboratories, and other users of light constantly encounter difficulties in securing proper illumination.

There are many phases of illumination in hospitals. First there is the general problem of illumination such as one may have under any condition. One problem is to secure a soft, uniformly dependable light, that will not be injurious or exert deleterious influence on the sensitive nerves of the eye, and one that can be relied upon to give uniform results.

Gas, under certain circumstances, is of course, available, and gives very satisfactory illumination. In hospitals, however, one of the most important objections to gas illumination is the inevitable vitiation of air unless adequate provision for ventilation has been made. Although it is not difficult to install and is often advantageous, few hospital wards are supplied with a system of gas lighting that can be fully endorsed. It has also the defect of introducing heat currents, and these are known to disseminate infection. Air currents carry dust, consequently bacteria—factors which enter prominently into the dissemination of disease. It has been shown that where heat currents communicate from one part of a building to another, infectious diseases are readily transmitted. This is especially true of measles, which is one of the most communicable of the infectious diseases. For general

* A paper read at a meeting of the Philadelphia section of the Illuminating Engineering Society, December 15, 1911.

illumination one should, therefore, consider a soft light, without glare, and yielding a minimum of heat.

Another factor is the influence of glare, especially upon the retina of the debilitated or depressed; their susceptibility to light is often extreme. Consequently the growing system of indirect illumination is being introduced. Such lighting for hospitals is used very little in this country; I have not been in any institution in which indirect lighting has been exclusively applied. Diffuse lighting has been attempted in operating rooms, and by a system of skylights the hospital authorities have endeavored to exclude shadow and glare, which of course are of the best evidences of diffuse equalized distribution of light. I know of no hospital in which the artificial lighting is above criticism. Even in the Jefferson Hospital, Philadelphia—one of the most modern institutions—the lighting possesses the usual deficiencies. The lamps are so situated that if they were brilliant enough to be useful, they would be highly objectionable; they are in frosted domes that soften and diffuse the light rays and look well, but are not to be commended.

It seems to me that if the principle used in the Congressional Library and in the Washington Railroad station could be applied to ward lighting, much would be accomplished for the comfort of patients in the hospitals.

It has occurred to me in this connection that an indirect lighting unit with a direct reflector might be used. I have not seen the idea applied. Arc lamps, the lower ends of whose globes were darkened, might be suspended so as to provide a soft light without glare. But sometimes a bright light must be thrown almost instantly on a section of a hospital. For instance, a patient is seized with a sudden hemorrhage. If the reflecting piece were made in a hemisphere and divided into two sections, so that the hemisphere could, by pulling a chain, be thrown into one direction or another, and obtain from above a direct light with its stronger illumination, one could secure, with the hemisphere below, a soft reflected light. I have talked this over with different manufacturers and generally they would be glad to make them if the hospitals would order about two millions at four times the cost of production.

The average doctor and hospital administrator want something; but are not certain just what it is; consequently no two of them appear to desire the same thing. A doctor reads in a medical journal of a certain apparatus, worked by a certain motor of a certain horse-power, and he imagines that anything else would be a transgression of some idea that he holds in his own heart, and therefore he must send to Oshkosh or some other place to some man who has a little shop and makes it; and after he gets it he finds it is not adapted to his purpose, and wants something else. That is the difficulty with the imported apparatus for lighting and for other purposes.

One device, a combination lighting and signal system, which is used in many hospitals consists of three lamps. One lamp indicates a lamp over a bed in the hospital ward; another lamp represents a lamp by the nurse's desk, and a third is a signal light in the hall. If a patient in any bed pushes a button he thereby lights a lamp at the nurse's desk, one over his bed, and one in the hall outside the ward. The lamp over the bed indicates the patient needing attention. There is no way by which the nurse can evade this call or put out the lamps, except by going to the bed and turning off the lamp. The lamps are not operated in series, so that one or any number may be in use concurrently or separately.

Another system working on the principle of the railroad semaphore has been used. This is also adapted to the private room services. The first mentioned plan of course works on a private room system as well as on any other. The semaphore system lights a lamp, rings a bell and drops a signal, so that there are three things upon which the nurse may depend for a call. In any installation one or more of the features may be omitted; usually the bell is left out. In the combined semaphore system there is an annunciator in the nurse's room or over her desk. The semaphore drops at right angles just above the door, and at the same time a lamp is lighted. In order to reset the system, she must go and set the semaphore in place, which at the same time puts out the light and sets the call on the register.

In addition to the signal system there has been suggested a clock-work attachment by which the length of time before the

semaphore is reset is automatically recorded, and therefore is a check on the nurse. It is operated, however, by a photographic filament and is analagous to the system used in the steamships for recording a response in the engine rooms.

Ward lighting also involves the question of the exact color and shade of light that is most beneficial. Upon this subject there has been much discussion but nothing conclusive. Whether the light should be green, yellow, or soft white remains undetermined; some strongly contend that it should be purple.

The attention of illuminating engineers should be called to a difficult problem, which exists in practically every hospital operating room; really it is a combination of all sorts of lighting problems. In the first place the quality of the light must be considered. For example, in operating upon a jaundiced patient whose tissues are yellow and whose blood serum permeates all the tissues of his body, carrying and implanting the yellow tinge, a yellow light cannot be used. During operations for gall-stones, yellow bile ducts, red arteries and blue veins must be distinguished. Often on account of the lighting conditions it is difficult to distinguish an artery from a vein, and while it may not be a matter of immediate importance to the operator, it is to the patient, because the surgeon may open the wrong channel. In daytime there is little trouble; the difficulty is with artificial light. This is true of nearly all forms of incandescent lighting, although the tungsten filament lamp is a great improvement over the old carbon form. Difficulty is also encountered with the use of gas light; attempts have been made to overcome these by placing color screens or filters in front of the light sources and also by using certain gases which may under some circumstances be useful; but they nearly all fall short of the requirements and there is danger of drifting into the blue shades which still further complicate matters.

The design of lighting fixtures for operating rooms is a pertinent subject. The need of more efficacious fixtures for such rooms is discussed briefly in the following paragraphs.

In an operation like that shown in fig. 1, where it is necessary for the surgeon to view the intestines of a patient the need of satisfactory lighting is evident. By any system it is difficult

to light abdominal recesses. In places the light provided by present systems appears too bright, while the recesses remain dark. Practically no fixture at present in use gives sufficiently widely distributed and properly directed light of an adequate candle-power. The difficulty here is that the light cone falls into a well, as indicated by the illustration, so that the margins

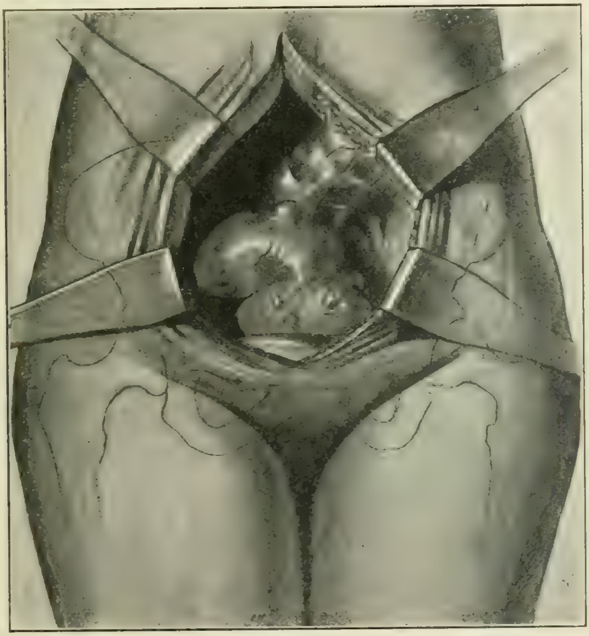

Fig. 1.—Tumor of womb. The lighting difficulty here encountered is to illuminate the deep intestinal recesses, particularly the one at the left. This requires intense vertical illumination coming from more than one direction in order to avoid shadows.

of the wall cast the deepest shadows. The ideal light, therefore, would provide for the deeper recesses in every direction. There must be provision for light passing obliquely in two directions; it is evident that the most difficult portion of the operation is often that requiring such a light; for instance, the procedure of separating the uterus from other structures.

In fig. 2 the surgeon is shown passing into the most difficult part of the operation, and into the field in which he has the least

light. Here, I think, the illumination has been greatly improved by the use of a hand lamp in the care of an experienced nurse or assistant; this procedure is the custom in many operating rooms. Of course such an arrangement falls far short of the requirements; the light should be there at all times and not during an emergency only.

Another difficulty of lighting an operating room is emphasized with the patient in a horizontal position, as shown in fig. 3.

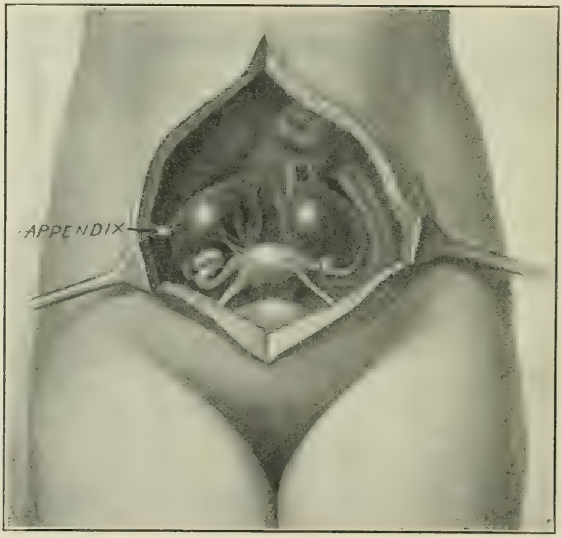

Fig. 2.—Operation on inflamed ovaries and tubes. Light must be vertical (overhead) and intense intense in order to illuminate the deeper recesses of the abdominal cavity. As these recesses are often in the shadow it is desirable that the light should come from more than one direction.

More accurately, the position is not horizontal, but the operator's field is in a vertical plane, consequently any light coming directly downward cannot afford adequate illumination. Every operating room should afford a light that may be directed at one end rather than at the top of the patient. As soon as this operation is begun and the skin is cut through, the instrument goes into the darkest recesses not reached by any forms of fixed lighting at present in vogue.

Fig. 4 shows an operation for an abscess behind the womb.

The fingers are pressing in the floor of the pelvis and the ends of the fingers are engaging behind the womb; at this stage, before bringing the uterus down, most of the work is so much in the dark that great skill is required in recognizing by touch many of the structures that cannot be seen.

In operations for appendicitis also the need of effective light is often realized. In many operations, preceding the removal

Fig. 3.—Method of examining neck of womb through the vagina. In operations upon this structure the lighting must be practically horizontal aud very intense in order to reach the depth of the vagina.

of the appendix, the surgeon does not see the tissue that he is excising.

Fig. 5 shows a typical operating room. The walls are all white; the side light and the skylight are fitted with diffusing glasses. In other words, an attempt has been made to adapt the photographer's method to the lighting of an operating room. The lighting fixture is made of steel with the lamps arranged radially around the center, and with one central pendant light. The photograph shows no shadows in the room; the table legs cast no shadow. Often the lighting engineer considers he has accomplished what is necessary in lighting if he has obviated the shadows, but still it is far short of what is desired in the way of

lighting. As arranged, the light is of no value in illuminating the intestines of a patient in operations like those which have just been mentioned.

The receiving ward of a hospital is shown in fig. 6. The walls are white and the whole room affords good opportunity for excellent reflection of light; there is no daylight. The illumina-

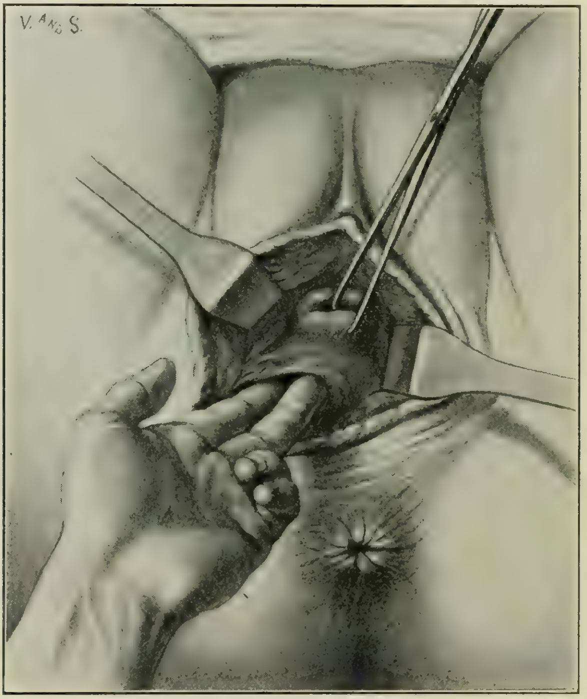

Fig. 4.—Operation of the vagina, opening an abscess posterior to and below uterus. This operation requires intense horizontal illumination.

tion in my opinion is not only wrong but also unsightly. The fixture should not be placed directly over the operating table. This point I consider important and should be insisted upon.

Fig. 7 shows another operating room which is round in plan. The shadows are reduced to a minimum.

Several types of fixtures have been designed for operating rooms in which diffusing glass has been used, the fixture being

hung over the operating table, but I am not familiar with one that has proved satisfactory, even though the diffusing glass seems to give intense light at the very points desired. In practice such devices have been defective.

A novel method of lighting operating rooms was devised by engineers connected with the Carl Zeiss works of Jena, over five years ago. The form shown in fig. 8 has not received an entirely cordial reception in this country; abroad it is highly praised. The European operator is practical and methodical, never hurries,

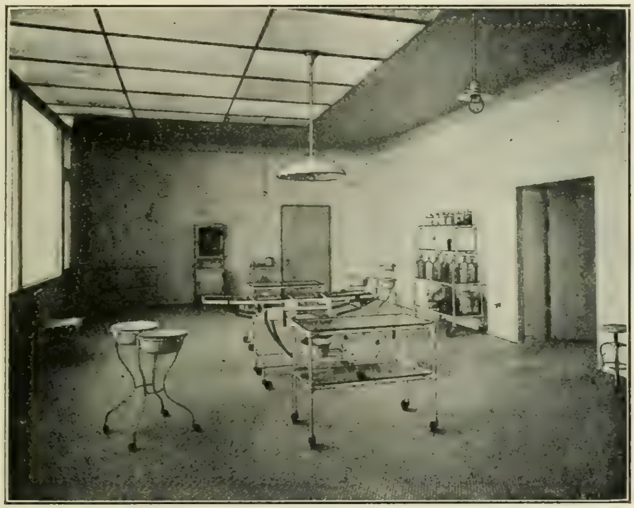

Fig. 5.—Typical hospital operating room. Jefferson Hospital, Philadelphia, Pa.

and does not care whether he gets through to-morrow or next day; the American, on the other hand, with his usual haste, is not likely to be overly enthusiastic about this particular light. The method is essentially a form of searchlight illumination. At one point is arranged a support upon which are grouped a cluster of mirrors. From a searchlight, placed outside the operating room, a beam of light is thrown upon the disk of mirrors, and from this point the light is directed to other mirrors. All of them may be lighted simultaneously, or any one may be used to the exclusion of all others.

The difficulty with this and similar methods of illumination is

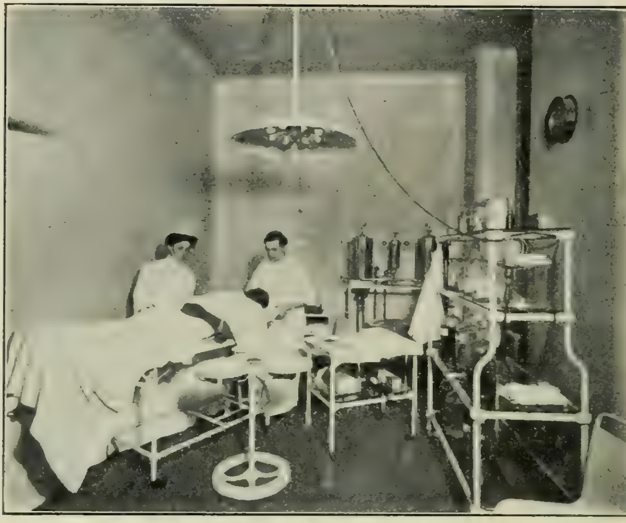

Fig. 6.—Receiving ward of Jefferson Hospital, Philadelphia, Pa.

Fig. 7.—Hospital operating room. Daylight illumination from the side only.

that all the mirrors require cleaning and that many have to be adjustable for changes in height as well as for other planes. Obviously, it becomes a difficult problem to secure exactly the

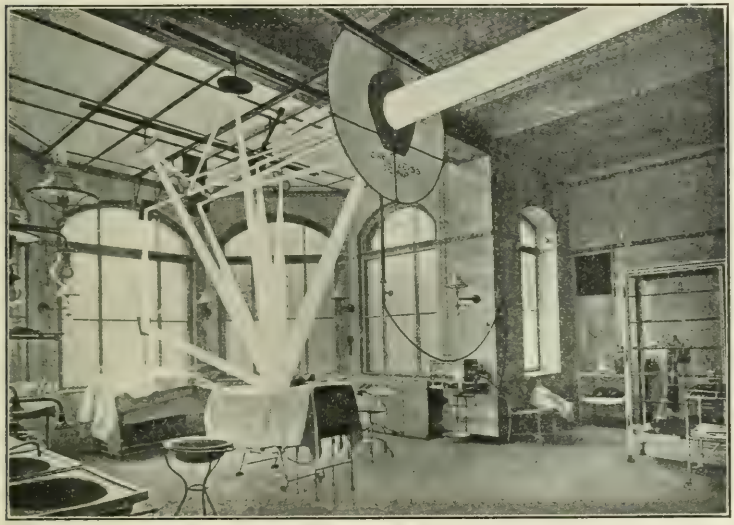

Fig. 8.—Hospital operating room equipped with one form of Zeiss lighting apparatus.

right arrangement in any particular case, and once it has been secured, each cleaning alters the position of every mirror.

In this paper I have only tried to set forth briefly some of the lighting problems that are at present encountered in hospitals. The problems, with their attending difficulties, may be found in nearly every hospital. I am sure they deserve the attention and careful study of the illuminating engineer.

DISCUSSION BY PHILADELPHIA SECTION.

Mr. W. F. Little (communicated) :—At the request of those in charge of this meeting, and through the courtesy of Dr. Fisher of the Presbyterian Hospital of New York City, I had the opportunity to measure the illumination produced by a Zeiss illuminating outfit for the lighting of operating tables installed in that hospital.

In the literature describing this equipment no mention is made of the illumination values.

The system consists of a high candle-power arc lamp placed some thirty feet from a cluster of seven mirrors on the opposite side of the operating table. The lamp is equipped with a properly designed lens to concentrate a pencil of light on the mirror cluster. One of the mirrors reflects the light directly upon the table at a relatively large angle to the vertical, while the remaining six reflect the light in six secondary mirrors which in turn redirect the light upon the same spot, about one foot in diameter, on the table, at a small angle to the vertical. The six secondary mirrors are mounted 10 to 12 feet above the center of the table and arranged in a rectangle approximately 10 by 15 feet, with the extra mirrors on the short sides of the rectangle. The short sides are in the direction of the mirror cluster and lamp. Thus it is natural to expect a very high vertical illumination in the direction of the mirror cluster.

It was found that the Zeiss system under the ordinary working conditions, namely, with the lamp rheostat at its midpoint, the illumination produced was as follows:—

ILLUMINATION VALUES IN FOOT-CANDLES ON THE OPERATING TABLE.

	Foot-candles
Horizontal	240
Vertical in the direction of the mirror cluster	250
Vertical 90 deg. to the mirror cluster	97
Vertical 180 deg. to the mirror cluster	95
Vertical 270 deg. to the mirror cluster	92

MR. C. O. BOND:—While the several speakers have been mentioning lighting installations in which the desire has been to throw the light to the ceiling, by the indirect method, they all seem to take it for granted that the light and the reflector must remain fixed with reference to each other. I have recently experimented with reversible reflector, an outline of which would more or less resemble an hour glass. It slides up and down vertically; the light remains fixed, and its reflector is counterbalanced; so that you may have direct or indirect illumination, or both, or the proportion of each may be varied. That seems to me would answer very well in the position of which Dr. Coplin has spoken.

It would not be very difficult to arrange a reflector of that sort for the nurse going up or down through the sick chamber to get either the direct or indirect illumination desired.

Mr. G. H. Stickney:—Dr. Coplin's paper has spoken of two principal problems; first, the lighting of the ward, and second, the lighting of the operating room. Taking up first the question of the lighting of the ward, there appears to be a growing tendency among illuminating engineers toward two schools of practise, one which believes rather strongly in indirect lighting, and the other in direct lighting with diffusing arrangements. Between these two is still a third practise, which is sometimes referred to as "semi-indirect" lighting. Good installations have been made in accordance with all three practises.

We hear considerable about the elimination of shadows. We must remember, however, that shadowless illumination is neither pleasant nor effective for seeing. The play of light and shadow on a curved surface assists greatly in seeing the contour of the object.

I believe that the indirect method of lighting has been applied to a considerable extent in some of the New York hospitals. I have not seen any of these installations, but happen to have heard a number of people who criticized the effect obtained. A strong light on the ceiling of a hospital ward does not seem desirable, and in this connection we must remember that the conditions are different from those which obtain in an ordinary room. Usually one does not have occasion to look much at the ceiling; in a hospital ward, however, where the patients are lying on beds, they are practically compelled to gaze upward toward the ceiling a good share of the time; so that a strong ceiling illumination is likely to be extremely irritating. And especially when one considers the conditions under which people are in a hospital, it is especially important that every condition should contribute toward their physical and mental comfort.

One method of ward lighting which has been used to some extent, and which appeals to me, is obtained by providing a moderately low intensity of illumination by any one of the three methods mentioned and supplementing this by local illumination at each bed. The local light can be located above the head of the

bed, supported either from the wall or from the bedstead, in such a position that the direct light must necessarily strike the face of the patient from above and thus be unobjectionable. This light should be properly confined and diffused so as not to produce glare either in the eyes of that particular patient or any other. This light will provide well for reading, the making of examinations or dressings, and can be cut out when not in use.

Now in regard to the lighting of the operating room, I feel that I have a very much better understanding of this problem since I have heard Dr. Coplin's paper. He has given us a splendid idea of the requirements of this class of lighting. I have also been interested in the different lighting devices which he has described. The combination of the searchlight and mirrors is particularly interesting and should give a splendid intensity and color of light. It seems to me, however, that there is one serious objection to it, and that is, that the failure of one light source at a critical time would be likely to stop the operation and endanger the life of the patient. The heat radiation and dust collection seems to be one of the most serious objections to most of the lighting equipment now available. It occurs to me that a ring of parabolic reflectors and tungsten lamps, similar to the automobile headlight equipment, could be arranged somewhat after the manner of the mirrors described for use with the searchlight. Very intense beams of light are thus obtainable, and, since each one of the lamps consumes only about 15 watts of power, the heat radiation will be relatively low. The lamps can readily be applied where alternating current is available, but as they are low voltage lamps, some arrangement would have to be made to operate them on direct current.

The color of the light might not be quite as good as that obtained from the arc searchlight, although this could be easily improved by the use of a color screen similar to that designed by Dr. Ives.[1]

It is quite possible that some diffusion may be necessary. This could be obtained by means of an external reflector, or by introducing a lightly diffusing window in front of the reflector. As this arrangement seems to more nearly meet the requirements of lighting an operating table than any other arrangement de-

[1] H. E. Ives. TRANS. I. E. S., Vol. VI, p. 872.

scribed. I would like to ask Dr. Coplin if he sees any objection to its use.

Mr. C. O. Bond:—The impression seems to be abroad that indirect lighting necessarily means lighting from the ceiling. If I remember rightly, these hospital beds are placed in a line, each between windows. Why not use indirect illumination from the side walls at the head of each bed? If there is a light tinted wall then with a mushroom-shaped reflector enough local indirect illumination can be had for each bed. That would closely resemble daylight illumination through the windows.

Mr. R. F. Pierce (communicated):—I have read Dr. Coplin's paper with great interest. Not having had the privilege of attending the meeting at which the paper was presented, I have not seen the slides and am unable to mentally construct or visualize the operations described to a degree that would enable me to comment upon this subject. After reading Dr. Coplin's paper I cannot help being impressed with the idea that probably the most difficult problems in illuminating engineering will be encountered in hospital lighting.

In speaking of the lighting of wards, Dr. Coplin refers to the objectionable qualities of heat and lack of ventilation, with especial reference to the production of bacteria laden air currents by the heat of gas lamps. Now it is well known that gas lamps accelerate ventilation to a marked degree, and so far as they are objectionable in producing air currents, they must be regarded as desirable from the standpoint of favoring ventilation. In the second place, the air currents of relatively high velocity produced by gas lamps are directed upward, where they diffuse over the ceiling, where the layer of warm air constantly tends to diffuse through cracks and pours into the outer air. These currents cannot be regarded as being objectionable as slower horizontal air currents of similar volume, passing from one bed to another carrying infection. Furthermore, I have grave doubts as to whether the horizontal currents required for feeding the upward currents from gas lamps are sufficiently important in comparison with the ordinary air currents produced by the motion of nurses walking about in the discharge of their duties to be of determinable effect.

I have often noticed in smoking in a closed room that the lighting of a gas lamp, while producing currents of high velocity above and for a few inches around the lamp, did not produce any observable acceleration in the velocity in the air currents throughout the room.

A certain amount of acceleration of course must occur, but I believe that the purifying effect of the gas flame upon the air in the room, by incineration of bacteria and accelerating ventilation, will be found to more than outweigh the effects of the slightly increased air currents.

The effect of gas lights in this particular has been investigated by Dr. Rideal, of London, who found that the air in a gas lighted room was always freer from bacteria than the air in an electrically lighted room. The bacterial determinations were in every case negative with gas, and never so with electricity.

Furthermore, any ventilating system inevitably produces air currents in proportion to its effectiveness. Ventilation is simply replacing one quantity of used air by an equal quantity of fresh air, and must always involve air currents in the room of sufficient vigor to carry bacteria a considerable distance.

It appears to me that, assuming ordinary precautions against drafts, the danger of transmitting infectious diseases through the air cannot be reduced to any extent worth while, except by sterilizing the entering air and by constantly disseminating ozone in the wards. I do not see any other way in which bacteria may be destroyed as rapidly as given off by the patients and prevented from entering from the outside. I do not know what practical objections may exist against this method. Possibly the electrical production of ozone might be objectionable by reason of the production of oxides of nitrogen, but I understand chemical means of producing ozone are commercially available.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. FEBRUARY, 1912. NO. 2

COUNCIL NOTES.

The first meeting of the council of the present administration was held February 9 in the general office of the society in the United Engineering Societies' Building, New York. In attendance were V. R. Lansingh, president; E. P. Hyde, A. E. Kennelly, Louis Bell, R. C. Ware, George S. Barrows, H. E. Ives, Norman Macbeth, L. B. Marks, C. H. Sharp, E. B. Rosa, J. T. Maxwell, C. J. Russell, W. J. Serrill, treasurer; Arthur Williams, W. H. Gartley and Preston S. Millar, general secretary.

The usual monthly reports of the secretary and the chairman of the finance committee were received. For the committee on reciprocal relations with other societies, Dr. Ives presented a progress report.

In accordance with a recommendation contained in the report of the committee on reciprocal relations with other societies, the council authorized the holding of a joint meeting of the society with the Washington Architectural Club in Washington on March 12.

Various standing and temporary committees for the ensuing year were appointed. These committees are listed on the inside page of the cover at the back of this issue of the TRANSACTIONS. The president was also directed to appoint a special committee to consider and recommend suitable dates and places for the 1912 convention of the society.

A request for the establishment of a section of the society in Pittsburg was received from a number of members residing in the latter city. The question as to whether such section should be granted was referred to a committee consisting of several officers of the society who were to attend the initial meeting of the projected section on February 13.

Authorization was given for the rental of an additional room

in the United Engineering Societies' Building for office use. The annual rent of this room is $396. The purchase of furniture not costing more than $250 was also authorized.

Considerable discussion was devoted to ways and means of increasing the income of the society. Three possible sources of increased revenue were mentioned: one an increase in the annual membership dues; another the establishment of a company supporting membership, and the third an increase in advertising in the TRANSACTIONS. It was decided that for the present at least it was desirable to endeavor to increase the income from advertising.

Thirteen applicants for membership in the society were elected. Counting these members the number of members in the society totaled 1400.

The monthly meetings of the council during the rest of the present year will be held on the Friday morning following the second Thursday of each month, except during the months of July, August and September. All the meetings will be held at 10.30 A.M. in the general office of the society, 29 West Thirty-ninth Street, New York.

SECTION NOTES.

NEW YORK SECTION.

At the meeting of the New York section February 8, Messrs. Arthur J. Sweet and L. C. Doane, of the engineering department of the Holophane Company, presented a paper entitled "Choice of Reflector; Its Influence upon Illumination Efficiency and Depression in Visual Function."

The program of papers that has been arranged for forthcoming meetings is as follows:

March 14—"The Application of Photography to Photometric Problems," by Dr. H. E. Ives.

April 11—"The Lighting of Passenger Vessels," by L. C. Porter; "Mine Lighting," by Mr. R. S. Iremonger.

NEW ENGLAND SECTION.

A meeting of the New England section was held February 26. Street lighting was the subject discussed. Dr. Louis Bell, Prof. H. E. Clifford, Messrs. C. A. B. Halvorson, G. N. Chamberlain, H. W. Hillman and others contributed to the discussion.

At the meeting to be held March 25, Mr. Norman Macbeth will present a paper entitled "Competitive Illuminants from the Salesman's Point of View."

CHICAGO SECTION.

A meeting of the Chicago section was held February 22. Messrs. A. J. Sweet and L. C. Doane, of the engineering department of the Holophane Company, presented a paper entitled "Choice of Reflector; Its Influence on Illumination and Depression in Visual Function." The paper was also read at the February meeting of the New York Section. It will probably appear in the April issue of the TRANSACTIONS.

For the remaining meetings this season, which will be held in the Great Northern Hotel, the following program of papers has been arranged:

March 21—"The Influence of Spectral Character of Light on the Effectiveness of Illumination," by Mr. M. Luckiesh of the National Electric Lamp Association, Cleveland.

April 18—"Window Lighting," by Mr. J. Henninger.

May 16—"Office Lighting," by Mr. S. E. Church of the Sears Roebuck Company.

PHILADELPHIA SECTION.

The Philadelphia section continues to draw a large attendance at its monthly meetings. A picture of the January assembly is shown below.

At the February meeting 173 members and visitors were present. Prof. George A. Hoadley of Swarthmore College presented an excellent paper on "The Physics of Light." The paper was supplemented by a number of interesting experiments and lantern slides. Prof. A. J. Rowland of Drexel Institute gave the second

talk of a series of five talks on the "Essential Principles of Illumination" entitled "Candle-power." Prof. Rowland's series of talks will appear in subsequent issues of the TRANSACTIONS.

At the meeting to be held April 19, Mr. Elias Goldensky will present a paper on "Artificial Illumination in Portrait Photog-

January meeting of the Philadelphia section.

raphy." The paper will be supplemented by a number of practical demonstrations.

PITTSBURG SECTION.

The latest indication of the growth of the Illuminating Engineering Society is the accession of a Pittsburg section. In conjunction with a dinner at the Fort Pitt Hotel, Pittsburg, the first meeting of the new section was held February 13. In attendance were a large number of representatives of the local lighting and manufacturing companies. Mr. V. R. Lansingh, president, and several members of the council were present and addressed the meeting. Addresses were also made by Prof. H. S. Hower of the Carnegie Technical School; Mr. C. J. Mundo of the General Electric Company; Mr. R. B. Shover, president of the Association of Iron and Steel Electrical Engineers; Mr. J. S. Orr, gen-

eral superintendent of the Allegheny County Light Company; Mr. T. M. Trimble, chairman of the Pittsburg Chapter of the American Institute of Architects; and several representatives of the local professional societies, lighting, engineering and manufacturing companies. The general interest and enthusiasm manifested at the meeting in the work of the society seemingly indicated that the new Pittsburg section will become a very active section in the affairs of the society.

The establishment of a section of the society in Pittsburg is the result of concerted efforts of several members of the society residing in that city. Several months ago they undertook on their own account to canvass the local lighting, engineering and manufacturing companies to ascertain whether a Pittsburg section would be desirable. The idea was received favorably by nearly every man who was approached. About eighty-five non-members signified their willingness to join the society should a Pittsburg section be established. Subsequently a petition for a section was presented to the council, and later the section was granted. About one hundred and thirty members are affiliated with the section.

The officers of the Pittsburg section are as follows: chairman, Prof. H. S. Hower, care of the Carnegie Technical School, Pittsburg; secretary, Mr. C. J. Mundo, Oliver Building, Pittsburg; managers, Messrs. W. Edgar Reed, E. R. Roberts, S. B. Stewart, C. E. Clewell, and W. M. Skiff.

At the next meeting of the section which will be held April 4, at 8:00 P. M., in rooms of the Engineering Society of Western Pennsylvania, Oliver Building, Pittsburg, Dr. Joseph C. Pole, of the Cooper-Hewitt Electric Company, will read a paper on "The Quartz Tube Lamp." Arrangements have also been made to have a paper on semi-indirect lighting presented at the May meeting.

MISCELLANEOUS.

AN ACKNOWLEDGMENT.

The society is indebted to Messrs. P. Blakiston's Son & Company of Philadelphia for the loan of the first four photographs

which were used to illustrate the paper entitled "Institutional Lighting with Special Reference to Hospitals," by Dr. W. M. L. Coplin, in the January issue of the TRANSACTIONS. These photographs were from a manual on "Gynecology," by Montgomery (fourth edition), published and copyrighted by Messrs. P. Blakiston's Son & Co.

ERRATA.

The word "sufficient" in line 7, page 22, January, 1912, TRANSACTIONS, should read *insufficient.*

At the bottom of page 23, of the same issue:

$470.48 should read $470.84

$2689.57 should read $2889.57.

THE ARCHITECT AND ILLUMINATING ENGINEERING.[1]

BY R. M. TRIMBLE.

It gives me great pleasure to extend the greetings of the Pittsburg chapter of the American Institute of Architects to the new Pittsburg section of the Illuminating Engineering Society and to wish the new organization the greatest success and prosperity.

I am a firm believer in organizations of this kind, and consider them to be beneficial in many ways. It should be a source of great pleasure and profit to every man to belong to an organization composed of others of the same profession or craft. There is a vast difference between membership in such bodies and that in the ordinary social organization or club. It is worth much to have the opportunity of meeting our co-workers, without the feeling of business rivalry, and of discussing with them our mutual difficulties. There is pleasure in meeting our competitors on friendly terms; there is profit in hearing how others have solved the problem of the moment which is bothering us. There are numberless things which tend to make membership in the professional body both pleasant and profitable, but there are duties as well as pleasures which one should consider before joining such organizations. Many men join these bodies for purely selfish reasons, the only consideration being, of what benefit will membership in this body be to me, and if the benefit to them is not apparent, they do not care to become members. No organization can continue to exist, the majority of whose members are of this type; and no man should join an organization unless he expects to be of some benefit to it. He should be willing to do everything in his power to aid in the success of the body, and with such motives his membership will be valuable to the organization, and doubly valuable to himself; for a man gets out of an organization or business what he puts into it, in inverse ratio; that is, if he is willing to bear his share of the burden and to labor faithfully and conscientiously for the success of the

[1] An address before the Pittsburg section of the Illuminating Engineering Society, February 13, 1912.

body to which he belongs, the effects which he receives from such efforts will be greater than those he imparts. The faithful and efficient worker for others develops rapidly, and the growth of his mental powers is very marked. It is the history of the majority of organizations that the work in them is done by a few self-sacrificing men, who either from a sense of duty, from the pleasure they get out of the work, or from a desire for power, conduct the affairs of the organization; but in most cases it is not because they desire position or crave power that they assume the responsibilities of office, but because they are obliged to step in and do the work which the other members are too indolent or careless to bother with. This is true to such an extent that the majority of members will not even take the trouble to attend the meetings. They are willing and anxious to reap any benefits which may be derived from organized effort, if that effort is not made by themselves, but they are absolutely unwilling to take any part in the labor, or make any sacrifice, to assist in making these beneficial results possible. So that mere size is not the measure of success of an organization. A small body of devoted workers will accomplish greater results than a larger body in which the greater number of members are not active, and not only of no benefit, but positively a burden on the workers. But I did not come here to preach on the duties and obligations of your members, although this is rather a favorite topic of mine; I am here to tell you of the necessity of such a body as yours in Pittsburg, and of the advantages of such organization to the architect.

The great science of illumination has not in the past been given the consideration which its importance deserves, but recent indications point to an awakening on the part of the public to the importance of the subject, and to the remarkable results which can be achieved from the intelligent study of illumination.

The wonderful discoveries of the last few years have revolutionized lighting methods and made it possible to secure the most beautiful results.

In the past the lighting of buildings was not given the proper consideration. We all realized the necessity of good lighting, but beyond the placing of outlets of sufficient capacity to give

a reasonably good light, no attempt was made to go further into the matter and develop the beauties of artistic lighting, or the effects which might be obtained from the use of different types of lights.

The theatres were the pioneers in the struggle for artistic lighting effects; with the development of beautifully staged plays, came the necessity for elaborate lighting schemes, and the result that has been achieved is truly remarkable. The effects produced in many presentations are such as to make one believe he is in Fairyland and that the director by waving his magic wand produces results that are almost unbelievable.

Then the science of artistic illumination was wonderfully developed, and received remarkable impetus, through the great expositions that have been held in the last twenty years, in which by the aid of illumination buildings and groups of buildings, and which were beautiful in the light of the sun, became veritable fairy bower by night. The Chicago Fair of 1893 was the first of the great modern expositions which were held in this country, and the illumination by night added largely to the success of that beautiful white city. Next came the Pan-American Exposition at Buffalo, of which the electric tower was such a dominating feature. Then came the exposition of St. Louis, in which the lighting effects were still further developed; and I suppose that the anticipated celebration of the opening of the Panama Canal, which will be held in San Francisco in 1915, will mark the culmination of the art of the illuminating engineer in lighting schemes of this character.

In the illuminated signs which have been so largely and successfully used by advertisers in the last decade, effects have been secured which are marvelous, and which are a part of this wonderful age of aeroplanes, etc. Every fete or pageant given by municipalities is incomplete without novel and beautiful lighting schemes, which tax to the utmost the ingenuity and skill of the illuminating engineer who is called upon in each case for some wonderful effect which has never before been produced; and when the architect is called in to plan for such affairs, his first thought is of the lighting effects which must be attained, and it is necessary for him to have expert advice on the best methods

of securing these effects. These results could not be obtained without the advice of men of trained intelligence, who bring their wonderful skill to bear on the problems, which a short time ago would have been considered impossible of solution, and their success has been among the great achievements of this advanced age.

Again, the concealed lighting, and the indirect lighting of buildings are problems which require the most careful consideration of men skilled in the art of illumination, and the results achieved are in many cases wonderful, and more than worth any amount of study and expense.

It is, however, hardly necessary for me to attempt to tell a body of men of this kind about lighting effects, and how they are secured, for you know vastly more about the subject than a mere architect. I have simply been trying to lead up to the work of the illuminating engineer, and the necessity of his services to the architect. Although you may not believe such to be the case, the architect is, in general, a much maligned individual. He is usually a hard working, decent sort of a fellow, who is trying to make a more or less honest living. Many owners, contractors, and even illuminating engineers accuse the poor architect of every crime on the calendar, but they would have more consideration for him if they had to assume his position for a short time, and could come to a realization of the many trials of his lot. If they could but realize the number of petty annoyances to which he has to submit, and the many unnecessary demands upon his time, I am sure they would experience a change in their feelings toward him.

In the modern building the technical requirements are so many and varied, that it is impossible for one man to be thoroughly familiar with all of them. To give intelligent direction to a project it is only necessary for the architect to have sufficient practical knowledge of such subjects as will enable him to give proper direction to the expert called in to advise him, and to have a comprehensive grasp of the entire situation. The modern building bristles with difficult engineering problems, in concrete construction, in steel work, sanitation, heating and ventilating, power and electrical work; and to solve these problems,

there are engineers specializing in the different branches, who are making a life study of these portions of the work. Therefore, when the architect is confronted with difficult technical questions, it is necessary for him to consult with the experts who are familiar with these lines of work. But no matter how expert these advisers may be, confusion will ensue if there is not a guiding spirit to unite the different parts so that the result will be a harmonious whole. If the different engineers were turned loose on a project, the result would certainly be unsatisfactory, for each man is intent only on getting his work done in the manner he deems proper, and he cares for nothing but the successful installation of that work; so that a master spirit is necessary for every building to see that there is no conflict in the installation of the different parts. In fact, the architect is called upon to assume the position of a priest, whose business it is to unite the different parts in the holy bonds of matrimony, and assure the owner that the bonds are so strong that a divorce will never be contemplated on the grounds of incompatibility.

In designing every city building, consideration should be given to the results which can be obtained in the illumination of the exterior of that building in relation to its neighbors, to the end that when grand civic celebrations are held, the illumination of each building will be part of a general scheme, the effect of which when properly conceived and executed will be stupendous.

The architect is usually able to handle the simple problems of illumination with which he is confronted, but the science has so developed that problems arise which he is unable to successfully cope with without skilled assistance. If he is confronted with any of the difficult problems mentioned, and which may be entirely new to him, it is of great assistance to him to be able to summon the expert, to whom the problem may not be new, or who, from his fund of experience may be able to recall parallel cases which will assist in the solution of the present problem. It is worth much to have within call, the man whose aid will be invaluable in determining the number and type of lights required for different purposes. In short, there are numerous ways in which the cooperation and assistance of the illuminating engineer will be valuable to the architect of Pittsburg, and I trust

that the new organization will become so useful to the architect that he will make many calls on its members for assistance, and that once the proper relations are established between the architect and the illuminating engineer, they will become of such mutual advantage as to make each indispensable to the other, and to the people whom they serve.

AN EXAMPLE OF THE PRACTICAL USE OF TUNGSTEN LAMPS TO PRODUCE DAYLIGHT EFFECT.*

BY CLAYTON H. SHARP AND PRESTON S. MILLAR.

In the autumn of 1910 the writers were retained by the National Silk Dyeing Company to design and superintend the construction of an arrangement for illuminating with "artificial daylight" their display of various colored silks at the Paterson Industrial Exposition. This account of the work is given not because it illustrates any new principles in the art of illumination or of producing daylight effects from illuminants which have a different color tone, but rather as an instance of the application of these principles under emergency conditions, and as a record of the methods which were employed under the limitations and the peculiar conditions which existed.

At the time that the proposition came up, glass cases for containing the exhibit had already been ordered, but had not been delivered. The original intention of the exhibitors was to use the Moore carbon dioxide tube for purposes of illumination, but almost at the last moment they found that it was impracticable to do this, due, it may be said, to no shortcomings of the tube itself. In view of the fact that a prominent competitor had perfected arrangements to exhibit the results of their skill as dyers under the light of the carbon dioxide tube, the aforenamed company deemed it to be of the greatest commercial importance not to be outdone in the matter of accurate rendering of color values. The time was so short that it was impossible to do the amount of experimentation and construction which the situation really called for. It was necessary to take the three showcases which had already been ordered, and to make the best of the work of illuminating their contents by such arrangements as were available at short notice.

The dyed silks which were to be displayed were in the form of skeins covering all the practicable tints and shades of the entire

* A paper read at a meeting of the New England Section of the Illuminating Engineering Society, Boston, Janaury 22, 1912.

spectrum, and included purple as well. The arrangement was such as to conform to the well-known color circle. By the use of a very large number of tints, a very gradual blending of colors one to the other throughout the spectrum was obtained. This made it necessary that the light thrown upon them should have practically a daylight spectrum and that the appearance of white light should not result from the blending of a few colors only. That is, bright line spectra or spectra with marked absorption bands could not be tolerated.

The cases which were to contain these exhibits were three in number, two of which had dimensions of $92\frac{1}{2} \times 21\frac{1}{2}$ inches (2.35×0.55 m.), and one, $68\frac{1}{2} \times 21\frac{1}{2}$ inches (1.75×0.55 m.). All sides of the cases were of plate glass. The skeins were arranged on pyramids in the cases so that the cases could be viewed from any side. The angle ~~of the~~ pyramid was such that any light incident upon it from above fell at an angle of incidence of approximately 60°, but an observer looking into the case looked about normally upon the silks. Also the light of the room fell full and free upon the silks.

The exhibition room was visited in order to see what the conditions of general lighting might be there. It was found that the roof had a large skylight in a very advantageous position to throw daylight upon the silks. It was found also that plans had been made to illuminate the entire room very brilliantly with carbon filament incandescent lamps and with arc lamps. These conditions brought out two points: first, that the artificial daylight illumination on the silks would have to compare favorably with the actual daylight illumination through the skylight, inasmuch as it was the intention to open the exposition in the daytime as well as in the night time. It was evident, furthermore, that the artificial lighting of the hall might have a very disturbing effect upon the colors of the exhibit. The remedy for this condition was evidently to smother the effect of the other illuminants with the high intensity of the artificial daylight illumination. It was deemed necessary therefore that the illumination on the silks should be relatively high; at least 25 foot-candles were sought.

The choice of illuminants was rather restricted. The mercury-vapor arc, together with a sufficient number of incandescent lamps

to add the proper red to the light, was ruled out on account of the discontinuous character of the spectrum of the mercury vapor. The carbon arc and other ordinary arc lamps were ruled out on account of limitations of space. There remained as the next best choice the tungsten lamp. The light of the tungsten lamps would have to be passed through color screens to remove the excess of red and yellow and to bring up the composition of the transmitted light to a daylight value. Using a preliminary estimate of the amount of light which would be lost in this way, a computation by ordinary methods showed that it would be possible to put enough high candle-power tungsten lamps in the space directly over each case to produce the very intense illumination which was required.

The next step was to make a proper selection of color screens. In doing this, two considerations had to be kept in mind. One was to get the proper color value, and the other, to get the minimum loss of light. Inasmuch as the greater part of the light of the tungsten lamp consists of red and yellow rays, any production of white light by the absorption of a considerable percentage of these rays must result in very serious losses of light. It was necessary therefore to select absorbing screens which would produce the maximum color alteration with a minimum loss. Experiments were conducted at the Electrical Testing Laboratories on color screens. In this experimental work, although a spectrophotometer and an Ives colorimeter were available for color comparison, the urgency of the case was so great that the use of these instruments had to be neglected in favor of the simpler method of comparing the artificial daylight with natural daylight by the use of a Lummer-Brodhun photometric cube. This arrangement is quite sensitive in disclosing color differences, and probably served better the purposes of comparison than the more complicated instruments. However, the use of this method made it necessary to accept as daylight whatever light was available from the sky, and this, as has been shown by various observers, is extremely variable. Comparisons were made, however, with the color of direct sunlight and also with the light which came from the northern sky. Even so, the variations in the color of daylight from day to day and hour to hour increased the difficulty of the work.

As color screens, various materials were tried. With such green and blue glasses as were available, it was found possible to get a very good approach to daylight, but on account of the possible difficulties of getting a sufficient supply of satisfactory glass upon short notice other materials were tried. Colored celluloid was found to be unsatisfactory due to its very indefinite absorption limits. Finally, solutions colored with analine dyes, that is, the staining solutions used for coloring the bulbs of incandescent lamps, were tried. It was found that if a blue staining solution and a green staining solution were taken, and each thinned to the proper consistency, a glass coated 70 per cent. of its surface with the blue, 15 per cent. of its surface with the green, and having no solution on the remaining 15 per cent., served to modify the light of tungsten lamps and to produce a good match with daylight. The loss of light due to these screens was about 87 per cent. The actual color screens which were used were made up applying these stains in the above portions to sheets of ground glass. The colors were put on in narrow bands, and ground glass was used on account of its diffusing powers, so that at the short distance away at which the silks were placed the rays of light which had passed through the different portions of the color screen would be so thoroughly mixed that a white light would be the result.

In the practical carrying out of the scheme, an ornamental box was made to fit on the top of each of the showcases. This box was open on the top except for slats which carried lamp sockets. One hundred-watt clear bulb tungsten lamps were selected as the illuminants and each was fitted with a concentrating prismatic reflector. Lamps were selected which were rated at about 10 volts less than the nominal voltage of the line in the exposition hall, the idea being to operate the lamps at one watt per candle or better, thereby increasing their candle-power and improving the color of their light. In view of the large absorption which had to be expected from the screens, it was necessary to put in as many lamps as possible. The color screens as described above were placed on the top glass of the showcases so that all light from the lamps had to pass through them before reaching the goods displayed. There-

fore neither the lamps nor the color screens were visible to the ordinary observer.

The arrangement produced a very intense illumination of a quality and quantity very striking in comparison with that of the rest of the hall. Although under the severe conditions of service the lamps deteriorated with relative rapidity and the dyes of the color screens faded somewhat, yet the results were, from a practical point of view, satisfactory.

It goes without saying that the procedure outlined above is one which would be justifiable only in case of emergency; it does not represent in any way the authors' ideas as to the best or even a proper arrangement for the production of artificial daylight under ordinary circumstances. However, as an example of emergency illuminating engineering, and of the application of principles of which one often hears, but which seldom are used in the arts, it is hoped that this account may be of some value.

THE RELATION BETWEEN THE COLOR OF THE ILLUMINANT AND THE COLOR OF THE ILLUMINATED OBJECT.*

BY HERBERT E. IVES.

The designer of an artificial daylight for purposes of color matching must have three things clearly in mind: the essential differences between the various illuminants, the character of the color composition of natural objects, and the nature of the possible distortions in appearance producible by the various combinations of these. That variations in color occur under different illuminants is a matter of common knowledge, and has led, on the one hand, to the practise of matching colors only under the light in which they are to be used; and on the other hand, to efforts to duplicate artificially the most generally acceptable illuminant—daylight. Tables have from time to time been published giving in one column a color, described by name, and in parallel columns the resultant color, again by name, when different illuminants are used. Visual demonstrations on the same plan, in the form of color booths, with the same fabrics under different lights, are familiar to all.

The possibility of expressing these phenomena of color in definite quantitative relations has of course been evident to those who have studied the question of color measurement, but to the writer's knowledge this has not thus far been done. The present opportunity seems excellent for outlining the scientific manner of expressing the relationships in question, and at the same time for drawing some practical deductions applicable to the topic of artificial daylight or color-matching illuminants.

It is necessary to review first of all various systems of color measurement and nomenclature, for without a satisfactory system of measurement one is helpless. From the standpoint of measurement, three methods of determining and recording color are important. First, the spectrophotometric method in which the intensity at each wave-length is determined, either by refer-

* A paper read at a meeting of the New England section of the Illuminating Engineering Society, Boston, January 22, 1912.

ence to a standard distribution or in terms of intensity of radiation. Such measurements are not strictly color measurements at all, since an eye insensitive to color, or an instrument such as a bolometer may be used. But this independence of physiological factors makes spectrophotometric measurements the most definite and absolute that we have. Second, measurement in terms of three coordinates, called in the Young-Helmholtz theory the primary sensations, and designated red, green and blue. Such measurements may be derived either by applying the known spectral distribution of the three sensations to the results given by the spectrophotometer, or by proper use of the values obtained

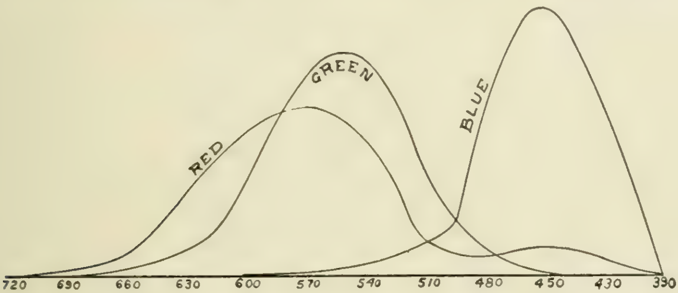

Fig. 1a.—Color sensations in white light.

from a color mixing instrument. Measurements of this kind, on different illuminants, have been presented before this society by the present writer. Third, measurement in terms of spectral hue, saturation (or mixture with white) and luminosity. The last method has been discussed in his paper "The Daylight Efficiency of Artificial Illuminants." Of the three, the one most suitable for the present purpose is the second, or three sensation scheme, the values being derived by the aid of spectrophotometric measurements.

The equation of any color may be expressed in trilinear coordinates, each representing one of the three sensations, red, green and blue. On the most usual scale white is represented as composed of equal quantities of the three sensations, distributed according to the determination by Koenig, fig. 1a.

If the red sensation be designated by R, the green by G, the blue by B, then any color is given by the equation:

$$(1) \quad aR + bG + cB = L,$$

where L is a number which may be conveniently identified with the brightness of the white or gray given by the same equation in which $a = b = c$.

The meaning of the equation is perhaps rendered clearest by constructing a color pyramid with a triangular base, fig. 2. For convenience let the altitude of the base be unity, then all colors for which L = unity are given by points on the base. Let the brightness or luminosity of the white, which is at the center of the base be called unity, and let it decrease regularly toward the apex B (black). All colors then lie on some section through

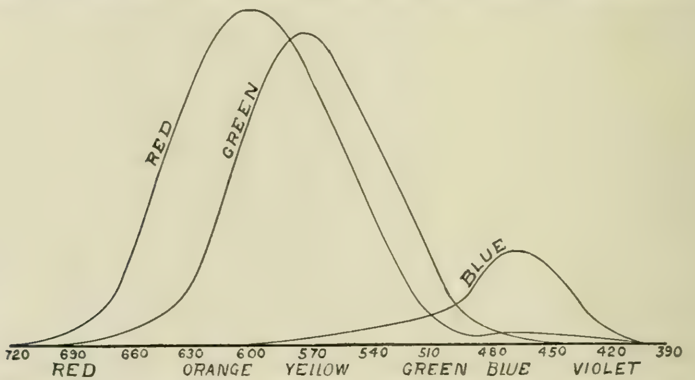

Fig. 1b.—Color sensations in incandescent carbon lamp light.

the pyramid. In discussing color alone it is most convenient to disregard luminosity differences and place all colors in a single reference triangle, for which L = unity.[1] This will be done in the present case. This pyramid with a triangular base is the one called for by the study of color mixture, and should not be confused with the square based pyramid of the psychologist which deals with the appearance of colors.

Let E_λ be the function representing the distribution of reflecting power through the spectrum of some colored object, where E_λ for a white object is unity. Let I_λ be the function representing the distribution of intensity in the illuminant, where again the distribution in white light is considered as unity and equal at all wave-lengths. Let R (λ), G (λ), B (λ) be the function representing the distribution of the red, green and blue sensation in

[1] The limitations imposed by changes in the shape of the sensation curves with changed illumination need not be discussed here.

the spectrum. Any color produced by the combination of the color of the object and of the illuminant is given by the expression:

$$(2)\ \int I_\lambda\, E_\lambda\, R(\lambda)d\lambda + \int I_\lambda\, E_\lambda\, G(\lambda)d\lambda + \int I_\lambda\, E_\lambda\, B(\lambda)d\lambda = L.$$

By using numerical values in this equation it is possible to determine the resultant color due to any given illuminant. For if I_λ is the spectral distribution of intensity in one illuminant and I'_λ that in another one has at once for colors under the two:

$$(3)\ \int I_\lambda\, E_\lambda\, R(\lambda)d\lambda + \int I_\lambda\, E_\lambda\, G(\lambda)d\lambda + \int I_\lambda\, E_\lambda\, B(\lambda)d\lambda = L$$

$$\int I'_\lambda\, E_\lambda\, R(\lambda)d\lambda + \int I'_\lambda\, E_\lambda\, G(\lambda)d\lambda + \int I'_\lambda\, E_\lambda\, B(\lambda)d\lambda = L.$$

To illustrate these equations the writer has made some calcula-

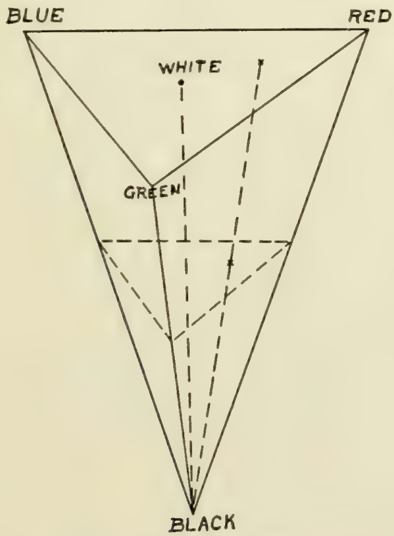

Fig. 2.—Color pyramid.

tions with certain arbitrary colors, using daylight and the light of a carbon incandescent lamp. The relative distribution of intensity in these two is taken from a previous paper before this society.[2] The constitution of the arbitrary colors is shown in fig. 3. where the shaded areas represent the selected portions of the

[2] H. E. Ives, Color Measurements of Illuminants; TRANS. I. E. S., vol. 5, p. 189.

spectrum. They represent possible but not usual colors, though ones comparatively easy to work with. They have in general the character of many colors met with in daily life; that is, their maxima extend over rather large regions of the spectrum, and a certain amount of light of all wave-lengths is present.

The results are shown in the large color triangle of fig. 4. The spectrum is given by the enclosing curved line with the vari-

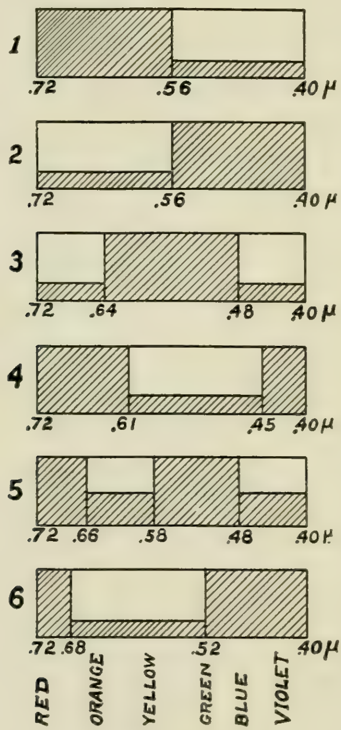

Fig. 3.—Spectral composition of certain arbitrary colors.

ous rainbow colors marked upon it. The colors under white light are represented by the letter *a*, the same under the carbon lamp by the letter *b*. The change in the color of the light source is shown by the two stars *a* and *b*, derived from the distribution of the three sensations as given in fig. 1a and 1b.

Examination of the diagram shows that, of course, truly mon-

ochromatic colors like those of the spectrum are unchanged (the only change possible is one of luminosity, which is not here dealt with) while the less saturated colors nearer the center of the triangle are shifted greatly. Now a line from the center of the triangle through the point representing the color, if continued, gives, where it intersects the spectrum, the dominant hue of the color. Applying this knowledge some interesting color changes are dis-

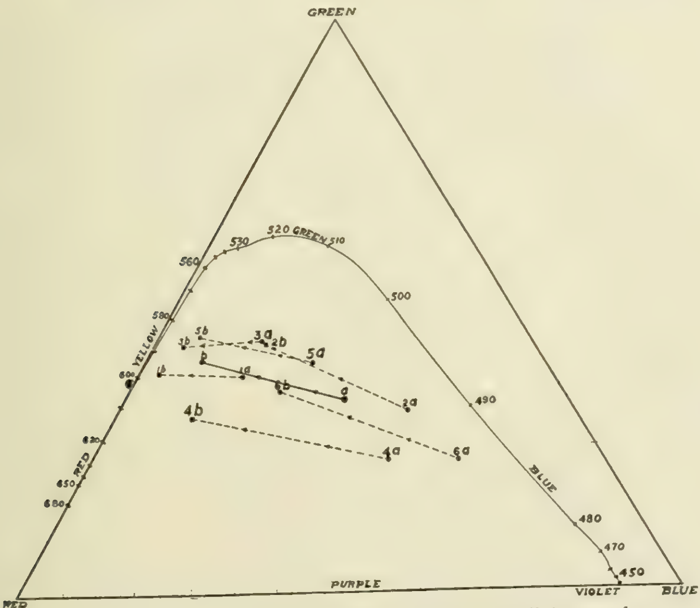

Fig. 4.—Change in color produced by change from daylight to carbon incandescent lamp illumination.

covered. A blue, for instance (2a and 2b), is changed to yellow; a violet (6a and 6b) to orange; green (5a and 5b) to yellow. Here, in fact, are expressed numerically the apparent colors of the same surfaces as seen on two sides of a partition, one side illuminated by daylight, the other by carbon lamp light.

Before leaving this topic a subjective element may be touched upon. After working for a time under a carbon lamp or other similar artificial light one ceases to notice that it is yellow. One apparently forms a new scale of color with unsaturated yellow as one's white. In this way compensation is introduced for the

really enormous changes in color, which actually occur. (Of course such compensation only occurs with unsaturated colors; the red light of the dark room never appears white). Just how to represent this compensation is a matter probably yet to be determined. It might be tentatively assumed, however, that the three *sensations* are somehow re-weighted. For instance, in the case of the carbon lamp, where the three sensations are excited in the ratios of

R	G.	B
50.9	40.6	8.5

the hypothetical compensation multiplies the sensations in the ratio of

$$\frac{33.3}{50.9} \qquad \frac{33.3}{40.6} \qquad \frac{33.3}{8.5}.$$

If now this same compensating process is applied to all the

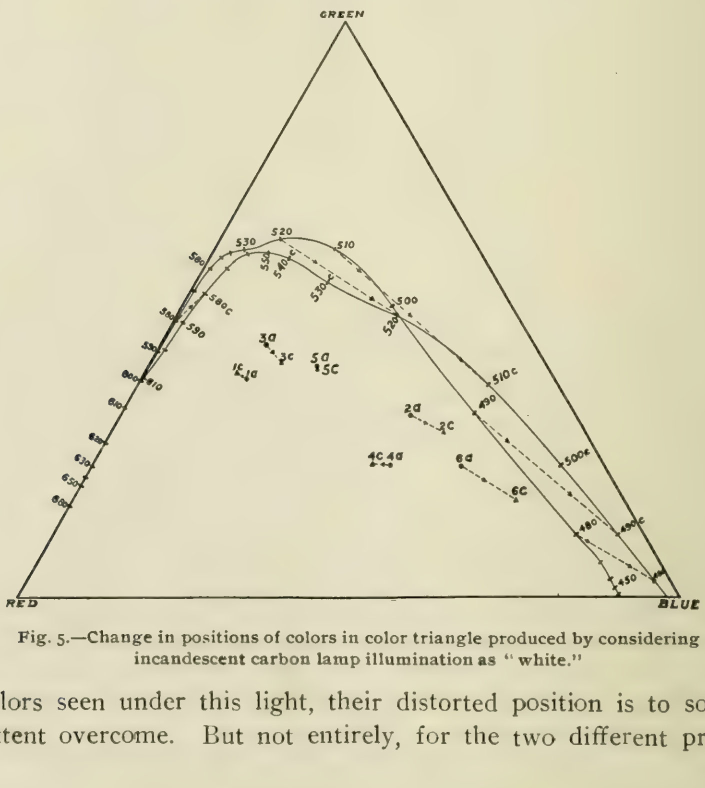

Fig. 5.—Change in positions of colors in color triangle produced by considering incandescent carbon lamp illumination as "white."

colors seen under this light, their distorted position is to some extent overcome. But not entirely, for the two different proc-

esses of color-change, one by change in spectral intensity distribution, the other by change in relative sensation intensities, never quite match. In fig. 5 the letters *c* denote the compensated color, on this tentative suggestion; which is not meant to do more than indicate the direction of the compensating process that does actually take place. It is seen that on the assumptions made some colors are, as it were, more than brought back to their original positions (2 and 6), others not entirely (1 and 4). The spectral colors are much shifted, the blues in particular being made of greater saturation. This diagram in fact illustrates qualitatively what is known otherwise as color contrast.

The element of luminosity or brightness should also be mentioned here. Besides the color changes noted there is a depression of luminosities in the deficient spectral regions of the illuminant, an exaggeration in the excessive regions. These changes may be treated in a manner similar to the color changes, by using the luminosity curves of the illuminants in conjunction with the distribution of reflecting power in the spectrum of the surface.

The question of color matching may now be considered. There will be a match on the two sides of our partition if the three sensations are excited in a like amount on each side, *i. e.*

$$(4)\quad \int I_\lambda E_\lambda R(\lambda)d\lambda = \int I'_\lambda E'_\lambda R(\lambda)d\lambda$$

$$\int I_\lambda E_\lambda G(\lambda)d\lambda = \int I'_\lambda E'_\lambda G(\lambda)d\lambda$$

$$\int I_\lambda E_\lambda B(\lambda)d\lambda = \int I'_\lambda E'_\lambda B(\lambda)d\lambda.$$

These equations may be satisfied by several sets of physical conditions. For instance, two colored surfaces, spectroscopically different ($E_\lambda = E'_\lambda$) may match under one illumination ($I_\lambda = I'_\lambda$) but not under another; that is, two colors may be subjectively alike under one illuminant, but subjectively unlike under another. A true yellow, and a red-plus-green yellow illustrate this possibility. Again it is possible for two surfaces to match where each is under a different illuminant, that is, neither $E_\lambda = E'_\lambda$ nor $I_\lambda = I'_\lambda$. For instance in fig. 4, (2) under the incandescent lamp is nearly a match for (3) under daylight.

Usually two different problems are before the color expert; one is that of color appearance and the other that of color matching. Colors may easily continue to match, but change greatly in appearance under changed illumination. For instance, purples may change from bluish to reddish. The condition that two surfaces shall always match when under any common illuminant is obtainable from the equations (4). If $I_\lambda = I'_\lambda$ the equation is satisfied in general only if $E_\lambda = E'_\lambda$. The solution

$$(5)\quad \int I_\lambda E_\lambda R(\lambda)d\lambda = \int I_\lambda E'_\lambda R(\lambda)d\lambda$$

$$\int I_\lambda E_\lambda G(\lambda)d\lambda = \int I_\lambda E'_\lambda G(\lambda)d\lambda$$

$$\int I_\lambda E_\lambda B(\lambda)d\lambda = \int I_\lambda E'_\lambda B(\lambda)d\lambda.$$

which states that the two colors are physiologically alike under a certain arbitrarily chosen illuminant I_λ may or may not be a solution in other cases, but usually will not be. In short, spectrophotometric identity is necessary for this property. Examination of two apparently similarly colored surfaces with a spectroscope will show whether $E_\lambda = E'_\lambda$ and therefore tell whether their match will hold under all conditions.

The second problem, that of constant color appearance, is met by just one condition, namely restriction to one light source of constant spectral character. This rules out a possibility which might suggest itself, that is, the use of another illuminant of the same integral color. But by reference to equations (4) it is evident that if when $I_\lambda = I'_\lambda$ (equations 5) the equality holds, it does not necessarily hold for an illuminant I''_λ for which

$$(6)\quad \int I''_\lambda R(\lambda)d\lambda = \int I_\lambda R(\lambda)d\lambda$$

$$\int I''_\lambda G(\lambda)d\lambda = \int I_\lambda G(\lambda)d\lambda$$

$$\int I''_\lambda B(\lambda)d\lambda = \int I_\lambda B(\lambda)d\lambda,$$

that is, an illuminant of the same integral color. It is, for instance, easily possible to make a subjective white, as by a mixture of monochromatic yellow and blue light. A white surface under this would look as it does under "daylight" but hardly a single other color would. It is therefore not sufficient to pro-

duce an artificial daylight which measures correctly on a color mixing instrument; the spectrophotometer is indispensable, although a colorimeter is in practise a valuable adjunct.

A few concluding remarks may be made on the practical realization of "artificial daylight" by the subtractive or absorption method. The problem is to combine with an artificial source absorbing media whose transmission is the reciprocal of the spectrophotometric curve of the source compared with daylight. The practical problem is that of the proper choice of artificial illuminant and of absorbing media,—given the previously determined spectrophotometric relationship between the artificial illuminant and daylight. As to the choice of the artificial illuminant to be screened to resemble daylight, two desiderata may be mentioned: first, it should itself be as near daylight in character as possible, so as to keep at a minimum the loss of light produced by the use of absorbing media; second, its spectrum should be as free as possible from irregularities such as bright emission bands or dark absorption bands, difficult to eradicate by ordinary absorbing media. Concerning the absorbing media, two kinds only are very practicable: colored glasses and dyed films, either of gelatin or collodion. Dyes have two disadvantages: their absorptions are apt to be rather narrow and they are liable to fade. Colored glasses are subject to the objections that the number of absorptions obtainable is quite limited and that they are not so transparent in their less absorbing parts as are dyed films. They are, however, very permanent and for that reason should be utilized to the fullest extent possible. The practical problem therefore becomes one of combining and compromising, using glasses where possible, and supplementing by the most permanent dyes obtainable.

An example of such an artificial daylight is the combination described by the writer and Mr. Luckiesh. In this the tungsten lamp is screened by a combination of cobalt blue and signal green glass assisted by a dye to absorb some transmitted yellow-green light. This combination has of necessity a very low efficiency, since the absorption is chiefly of orange and yellow light which contribute the largest part of the luminosity of the tungsten lamp. The compromise with the ideal absorption derived from the spec-

trophotometric data is, however, small, and where the need is for an artificial daylight for color matching the low luminous efficiency of this type of light may be more than compensated for by its excellence from the standpoint of color.

For information on the general question of artificial white light reference may be made to the following articles:

Herbert E. Ives, "White Light from the Mercury Arc and its Complementary." *Bul. Bur. of Standards,* Vol. 6, No. 2, 1909.

Herbert E. Ives, "The Daylight Efficiency of Artificial Illuminants." *Bul. Bur. of Standards,* Vol. 6, No. 2, 1909.

Herbert E. Ives and M. Luckiesh. "The Subtractive Production of Artificial Daylight." *Elec. World,* May 4, 1911.

Herbert E. Ives, "Color Measurements of Illuminants, a Resumé." *Trans.* I. E. S., April, 1910.

A LAMP FOR ARTIFICIAL DAYLIGHT.*

BY R. B. HUSSEY.

Within the last two or three years there has arisen a considerable commercial demand for some form of illuminant that will give a steady light of fairly high intensity and a color effect closely comparable with daylight. This demand has come first from the manufacturers of colored goods of various kinds who want to be able to keep up their production independently of the weather or the season of the year. As a standard to which to refer, daylight is very unsatisfactory. As the word is commonly used, a mixture of diffused light from sun and sky is meant, but since there is so much difference resulting from differences in sky and weather conditions, it has become necessary, in many places, to have recourse to the light from a clear blue sky, preferably northern exposure, whenever color work of the greatest accuracy is to be done. To many, this may not seem fair, but as it represents the most nearly constant natural light source, it seems to be the most satisfactory standard of reference and is the one most frequently considered. Although indirectly from the sun, the sky light has a considerably greater proportion of blue and violet than sunlight and of course very much more than ordinary lighting units.

The different forms of lamps suitable for interior lighting which could be employed for correction to daylight are limited. Lamps of the incandescent class such as carbon and tungsten derive their light from a continuous spectrum strongest at the red or long wave-length end and weakest at the violet or short wave-length end. With these lamps the problem of obtaining a daylight effect is to reduce, usually by absorption, the excess of red and orange until the resultant light shall have the desired proportions. With flame arc lamps, having a bright-line spectrum, it is more complex and where the spectrum lines are not well distributed, it becomes impractical to say the least. An extreme case would be the mercury-vapor arc lamp where to

* A paper read at a meeting of the New England section of the Illuminating Engineering Society, Boston, January 22, 1912.

obtain a daylight effect would be practically impossible, owing to the large amount of light concentrated into a few wave-lengths.

In the enclosed carbon arc lamp or intensified arc lamp, one finds a combination of the two. The temperature radiation from the crater of the positive carbon is hotter than any form of incandescent lamp and hence whiter, though still not as white as sunlight, and superposed on this is the light from the arc stream which is mostly violet or short wave-length radiation. Thus the resulting light has an excess at both ends of the spectrum, the red and the violet, and to correct it to daylight both must be reduced with as little as possible loss in the middle of the spectrum.

As this lamp is in itself one of the best of ordinary interior illuminants for color work numerous experiments have been made to obtain with it a unit with true daylight effect. For an absorption medium, different kinds of colored glass were first tried but nothing was found with the desired absorption. Some experiments were made in staining glass with permanent colors that could be fired into the glass; but while a fairly satisfactory color was obtained the absorption was so high that there was not enough light left to be of very much value. Several colors of glass were, however, found with very nearly the desired absorption and starting with these there arose the question of how to combine the different colors so as to get the required result. Two methods were considered: first, to place the glasses in series, as it were, that is, put one on top of another and pass the light through one after the other and, second, to put the glasses in parallel or side by side and then mix the light coming through the different colors by some diffusing medium. This latter method was the one adopted since, though more complicated, it seemed to make a more flexible arrangement and enable one to obtain a finer adjustment of color effect with the same assortment of colors than could be obtained by the other method.

The construction of the outfit shown in the accompanying illustration is easily understood. A standard intensified arc lamp consuming about five amperes is used and a hood coated on the inside with aluminum bronze is attached to the casing so as to concentrate the light in a downward direction and also furnish a holder for the color screen. The color screen consists of a

single layer of colored glass composed of pieces about one inch square of three different colors. The separate colors are distributed as uniformly as possible and are placed on a sheet of clear glass. Immediately above this layer is a clear figured glass for diffusion; another glass for diffusion is placed about two inches below the colored layer. In this manner, good diffusion is obtained and no spotted effect can be detected. Each of the sheets of clear glass is cut into several strips to reduce the danger of cracking from heating and cooling.

Color matching outfit for direct current intensified arc lamp.

The whole forms a convenient unit that is easily installed and handled. The lamp itself is standard and requires no special treatment. Only a few of these units have so far been put into actual service, but they have been giving good results. With the amount of light absorption necessitated by such methods a good efficiency cannot be obtained. Of course such outfits are not intended for use in lighting stores or other large areas; but they may be used to light areas where the goods to be examined or compared can be brought.

DISCUSSION OF PAPERS OF R. B. HUSSEY, H. E. IVES, AND C. H. SHARP AND P. S. MILLAR.

DR. A. E. KENNELLY:—This subject is one of great fascination and interest. It represents an advance, in a practical way, over anything that could have been attempted a few years ago. It seems strange that we human beings who have been evolved to live in the light of the sun should have been obliged for thousands of years to dwell at night under illumination of a very different color. Of course it has been Hobson's choice. We took what was available, or we went to bed in the dark; but it seems as though it should only be necessary to indicate how to imitate daylight color at night, in order to stimulate designers and inventors to arrive at a practical and economical solution of this important problem, because from the æsthetic standpoint alone, without touching either the hygienic or the utilitarian views of the matter,—the value of an artificial light closely resembling daylight in color is manifestly very great. Of course there are two ways in which the problem can be attacked theoretically. Suppose that a number of ships of the same size, and built for the same purpose, are launched, but that they are sent to sea with very different compliments of crew. Instructions are then received by this fleet from headquarters that the personnel on board these ships shall be reduced to exactly the same percentage of distribution, no matter how many men they have on board. There are hereafter to be, say, 30 per cent. of coal-passers, 25 per cent. of sailors, 10 per cent. of officers, etc. Now it might happen that certain ships already possessed the required distribution exactly and no change of personnel would be needed for them, but other ships might possess a great preponderance say of coal-passers and a very small proportion of officers. Such a ship, in order to come up to the standard of percentages, would have two possibilities,—one would be to send officers to the required number from headquarters in order to annul deficiencies by bringing up the percentages, which would be a constructive process; or, to make the excessive coal-passers walk the plank, and so get rid of the superfluous number, annulling excesses. Of course the latter method would be a destructive method.

Naturally, the constructive method would be preferable, if it could be adopted. In the luminous examples we have displayed before us this evening, we have the destructive method illustrated, but I think we should not judge them harshly on that account, since we thereby attain the desired end. They are destructively constructive, or constructively destructive. The possibility of reaching the desired result even destructively is a great advance, and once it becomes the fashion to produce artificial daylight illumination, the urgency of doing so on a larger scale will probably increase. In certain parts of the world, for example in Great Britain, where they are compelled to sell power and not light, you can readily see how the power supply companies would hail with delight the chance of supplying electric power for artificial daylight, because they would be selling 100 units while the people got the equivalent of only 20 units in light. It is probable that such a destructive process would not be in vogue very long before constructive means would be arrived at to avoid the destruction and absorption of light. I think we must congratulate the authors of these papers in showing us not only a very interesting exhibit, but also a very practical means for doing what is intrinsically an important thing.

Dr. Louis Bell:—It may be interesting to the members of the society to know how old this scheme is. It probably antedates any of us by a very long time, but I remember at least thirty-five years ago that there were on sale and passed about the country in large numbers chimneys for kerosene lamps which were intended to reduce the lamp to a daylight value. It consisted of a very light blue chimney,—probably a very light cobalt glass, and I am bound to say that the effect in whitening the light was very conspicuous indeed. The chimneys were quite popular all through the country regions. I fancy in country stores some may be found now on the top shelf. The scheme, as I say, is a very old one and based on the belief that a white light was a desirable light. I am not altogether sure, and I do not want to speak disparagingly of the efforts of any of our colleagues, but I am not sure that the approximation to white obtained by some of the later devices is very much more precise than that obtained by the early lamp chimneys of which I speak, because all the

efforts I have seen to produce artificial daylight are not to produce the normal color of daylight but to produce a blue comparable with the sky, which is a very much easier matter in a sense.

All the artificial daylights I have seen have been distinctly blue. They have been intended deliberately to imitate the north sky on a brilliant day and a fine Italian sky at that. A good many shopkeepers like that particular kind of light, particularly those who have to dispense blue goods. A dealer in cloth loves a fine northern light and holds his sample up so you can get it from that sky. Whether the same device with the same set of screens will be satisfactory for tailor shops and for the ribbon counters of a dry goods store I have great doubts. I think we will find several kinds of daylight will come into use in the next year or two, each one adapted to display effectively the goods of the gentleman who orders that kind of daylight. I think we ought to have some average idea of what daylight really is before we try to go on a large scale into using it. This type of lighting,—and by the way it is interesting to note that both the experimenters who have described their work this evening have fallen into the same scheme of multiplying the light in parallel,—is one that has a very great advantage over most of those previously practised, in that it has really a continuous spectrum and does not break it up. The carbon dioxide tube which is a capital match for a northern sky in most respects, shows on very critical examination some weaknesses with particular tones, particularly brownish ones, due to the fact that the spectrum in the yellow is slightly discontinuous, and one cannot find colors under that light, which is a capital light for general purposes, that are not a little bit off when compared with the light of the northern sky.

The use of the continuous spectrum for any subtractive purposes is I think practically essential. The flame lamps are not anywhere near continuous. They show great discontinuities in the spectrum. The magnetite lamps are better; they give a fair distribution throughout the visible spectrum, but I am inclined to think that we have got to abandon all the discontinuous sources in favor of either a high intensity carbon arc or a high intensity incandescent lamp. I am surprised that mention has not been

made of the intensive arc, which comes very near to a good daylight source itself unless you specify that that daylight shall be blue daylight and not diffused daylight. I should imagine it would be a better subject on which to work than either the tungsten or the enclosed arc.

MR. P. S. MILLAR:—I want to express my appreciation of Dr. Ives' paper, which has been presented by Dr. Bell. It is one of a series of papers on the subject of color value of artificial illuminants, but it sets forth more definitely and clearly the possibility of working out this problem of artificial daylight scientifically rather than empirically, as some of us have attempted. Certainly the scientific method is in this, as in most problems, the logical method of attack. Then too, Dr. Ives has applied the scientific method to the practical problem and has devised a colored glass screening system which, when applied with tungsten filament lamps, produces what is undoubtedly a fair equivalent of average daylight.

One interesting and important point is the difference between the quality of daylight and our ordinary forms of artificial light. As we sit here to-night in a room illuminated by carbon filament incandescent lamps, I think most of you will agree that this daylight equivalent as designed by Mr. Hussey appears distinctly unpleasant. The device which Dr. Sharp and I have described was the subject of a similar comment under similar conditions. Notwithstanding this displeasing quality of this daylight equivalent, we are wont to esteem natural light in the daytime as of pleasing quality which it would be desirable to emulate in the design of our artificial light sources. Now this difference does not indicate failure of this daylight equivalent to approximate average daylight. It is probably a matter of adaptation.

At night most of us prefer such light sources as the incandescent electric lamp. Personally, for use in my home, I prefer the quality of the carbon filament lamp to that of the tungsten filament lamp. I would not consider installing in my home a light source such as that described in each of the three papers, one of which is displayed here this evening.

This problem of quality is undoubtedly intimately involved with the problem of quantity of light. In the daytime we require

10 to 20 foot-candles of daylight for good office illumination, while at night we are satisfied with 3 or 4 foot-candles of artificial light. The study of this question is to my mind one of the big problems that confront illuminating engineers.

The practical aspect of these attempts to produce artificial daylight is a matter of interest. It seems to me that in department stores, etc., there should be at least one room in which artificial light of average daylight quality should be available when desired. If either the artificial daylight or the unmodified forms of artificial light may be employed as desired, I should think that all purposes would be served. I question, however, if the general use of artificial daylight in such stores would be desirable. Many purchasers are more interested in the appearance of goods under common forms of artificial light than under daylight.

I am interested in Dr. Bell's reference to the lamp chimneys of some years back which when employed with kerosene lamps were supposed to give light of daylight colors. The thought occurred to me that if such chimneys really did modify the quality of the light from an oil lamp to the extent stated, it would be doubtful if they would ever be used or if the light would be appreciated, because the usual form of oil lamp is one which gives a little light of low efficiency, conditions which would mean that such chimneys would transmit extremely little light, so little indeed as to make the scheme utterly impractical.

With regard to the device described by Dr. Sharp and myself, I think that Dr. Bell in his discussion has labored under a misapprehension. We did not endeavor to approximate north sky light quality. We aimed rather at something between this quality and the quality of direct sunlight. However, any daylight equivalent viewed at night under such conditions as obtained in this room would appear to the eye relatively blue.

THE ESSENTIAL PRINCIPLES OF ILLUMINATION.*

1. *Light and Light Flux.*

Light is a wave motion invisible in air or in a transparent medium. It passes in definite directions by a wave motion. The waves have been carefully studied and their nature is well understood.

In order to get some clear notions upon which to base ideas of light and light flux, one may start by considering a very simple case of propagation of wave motion. If a flexible rope fastened at one end is vibrated up and down at the other, a wave runs down the rope. If a series of waves is set going, following each other in regular succession, something is passing down the rope, something to which a name has never been given. There is a propagation of waves in a definite direction; but the rope does not move in the direction the waves go, it simply furnishes a medium of transmission. A corresponding set of facts may be easily shown to hold for water waves. One may easily observe that such waves have a definite direction of propagation and that the water does not move continuously in the direction the waves go.

Most waves are invisible; sound waves, for example. A certain kind of wave is set moving through the air. It passes along with known velocity and in a definite direction. A motion of the air furnishes the means for propagation of such waves. As in the case already mentioned, however, the air simply furnishes the medium whereby the wave motion is carried. The something which passes along through the air as a wave motion has been named; it is called sound. There are many ways of noting the fact that sound waves pass in definite directions and reach distant objects after they leave those near by. Sensitive gas flames enable this to be shown, for they are responsive to sound waves. If placed some distance apart, a slight difference may be noted in the time of their response; although sound waves travel quite fast and so only a very brief time elapses between the response at the nearby flame and at the distant one.

* The first of a series of five talks (1. Light and light flux; 2. Candle-power; 3. Shades and redistribution of light; 4. Units of illumination and its calculation; 5. Principles of photometry) to be delivered at meetings of the Philadelphia section of the Illuminating Engineering Society, by Prof. Arthur J. Rowland.

In like fashion there is another sort of wave motion which when being propagated is called heat. By the use of radiometers and other simple apparatus it may be shown that radiant heat is passing by any point where the flow of heat waves is intercepted. The speed of the heat waves is too great to show anything to indicate to an audience that they reach near objects before they reach distant ones. But it can be shown by cutting off the transmission intermittently that the heat waves pass out from a source and are under control.

In a precisely similar way there may be a propagation of waves called light or light flux. A wave motion is created at a suitable source, flows out from it through a suitable medium, reaches one's eyes and produces at the point where it is arrested in them the sensation of light. Any object we see is visible because the light waves which strike it are intercepted there and proceeding thence to our eyes give the sensation of light. The enormous speed of propagation of this wave motion may be noted by erecting two light colored targets at some distance apart, and then when a light source is allowed to send flux toward them, which is interrupted intermittently, we find that they are rendered visible so nearly simultaneously that it is quite impossible to detect the fact that the distant one receives light flux after the one placed near by. It happens that light and heat waves are of the same kind.

Light flux may be due to wave motions of different length; in which case the sense of different color is produced in our eyes; or of different amplitude, which results in different intensity. No reference will be made to these matters in this series of talks, it being assumed that the light flux is of a character like that which proceeds from ordinary illuminants.

Light flux travels in straight lines. This may be shown by arranging a small opening in a screen before an electric arc light, and making the path of the light flux visible beyond the screen by dust particles. A small divergence of the beams shows all the more truly that the light is passing in straight lines from the source through the air. And it is a rather remarkable fact that a wave motion can be transmitted so directly and with such clear boundary lines through a medium which will transmit the flux

with equal ease in any direction. It might be expected that there would be considerable disturbance along the edge of the wave path, just as there would be in an opening from the side of a water channel along which a wave motion was being propagated. To a certain extent this does occur, as will appear later. The wave motion goes on indefinitely if not intercepted by an opaque object, except for the absorption of its energy by the propagating medium. This occurs in precisely the same way that the waves sent down a rope have their energy frittered away, as may be observed by their decreasing amplitude as the wave motion goes further.

As light flux proceeds from a source it spreads over a larger and larger area. This has just been illustrated in a limited way by the beam of light spoken of in the last paragraph. We may see this strikingly by arranging to bring an arc light quite close to a screen with a small opening in it. By interposing screens in the path of the divergent flux we may define the limits to which it spreads and see as well that there is a certain amount of disturbance along the edges of the direct path of light from the source. In the same connection one may note how the light proceeds in straight lines by allowing the shadow of a pencil to be cast on a screen. The intense black shadow shows that the flux is cut off by the pencil over a narrow clearly marked path from it to the screen.

The amount of light flux which passes from a source depends on the area of that source. Everyone knows that the light from an ordinary gas burner when turned up is more than when it is turned down, due to the larger area of the source. The amount of light flux from the source can be at once judged by comparing areas of gas flames. Or the facts can be shown by enclosing a source and allowing light from it to reach a screen through a slot whose width can be increased. As the slot is widened the screen receives more and more flux—is more and more brightly lighted.

The amount of light flux from a source also depends on the intensity (often called the intrinsic brightness) of the source. This we can readily see by noting how, with constant area of source as with an upright Welsbach mantle, turning on more gas

and increasing the intensity of the mantle results in increasing the light flux from it. Or it may be shown by an electric incandescent lamp if we note the increased light flux as shown on a screen, as the current through the filament is increased and its intensity increased.

Ordinary illuminants have very different intensities. If we compare some of them and put the intensity of other lights in terms of the ordinary gas flame, we have figures as follows:

Light	Relative intensity (brightness)
Ordinary tallow candle	¼
Open gas burner	1
Welsbach gas mantle	6
Tungsten lamp	125
Electric arc lamp	10,000

That is, for example, if a tungsten lamp is to give the same light as an open gas burner, the area from which the light would come would be only 1/125 of that of the flame. If the 20 candle-power flame has an area of 4 square inches, the tungsten lamp of 20 candle-power would only have an area of 4/125 or 0.03 square inch.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. MARCH, 1912. NO. 3

COUNCIL NOTES.

Seventy-nine applicants were elected to membership in the society at the meeting of the council which was held March 15. Most of these applications came as the result of the organization of the new Pittsburg section of the society in February. Thirteen resignations were also received, making the net increase in membership for the month sixty-six members. Counting these changes the membership of the society totaled 1,409 members.

In addition to the report of the secretary, monthly reports were received from the finance committee, the committee on financial policy and the committee on reciprocal relations with other societies. The report of the finance committee constituted an approval of the February bills amounting to $1,052.24. The report of the committee on financial policy embodied several suggestions as to ways and means of increasing the income of the society. This report was returned to the committee with a request for specific recommendations. The report of the committee on reciprocal relations outlined the activities of that committee in promoting coöperation with other organizations in matters pertaining to illuminating engineering. Included in the report was a list of the joint meetings with other societies that had been arranged by the committee.

To arrange for the papers on illuminating engineering subjects, which are to be read at a joint meeting of the society and the American Institute of Electrical Engineers during the convention of the latter organization in Boston next June, the following committee was appointed: Dr. C. H. Sharp, chairman; Mr. W. D. Weaver, Mr. L. B. Marks, Dr. A. S. McAllister and Mr. Bassett Jones, Jr.

A report was received from a special committee which had been appointed to consider places and dates for the 1912 con-

vention of the society. The report contained several suggestions both as to time and place, but it was referred again to the committee with a request that they make a definite recommendation to the council at its April meeting.

The work and scope of the research committee was discussed briefly. Dr. E. P. Hyde was asked to present a list of recommendations in this respect at the April meeting of the council.

President Lansingh was asked to communicate with the various colleges in the United States and Canada to ascertain what work they are doing in illuminating engineering.

Should the society reserve its TRANSACTIONS entirely for notable papers and discussions on subjects pertaining to illuminating engineering, and publish the general notes and discussions of its affairs, new items, etc., in some form of a monthly bulletin? Should abstracts of the society's papers be prepared for distribution to other societies and the technical press?—two questions of publication policy—were discussed briefly and subsequently referred to a joint meeting of the papers and editing committees which is to be held April 11.

The secretary read an announcement of the symposium in celebration of the centenary of the introduction of gas as an illuminant which is to be held under the auspices of the American Philosophical Society, The Franklin Institute, the American Chemical Society and the American Gas Institute in the hall of the Franklin Institute, Philadelphia, April 18 and 19, 1912.

President Lansingh was asked to appoint a committee of five to consider the standardization of the symbols used in plans for artificial lighting. Mr. Bassett Jones, Jr., was nominated as chairman of the committee.

Those present at the meeting were V. R. Lansingh, president; J. R. Cravath, C. J. Russell, L. B. Marks, E. P. Hyde, Norman Macbeth, H. E. Ives, A. J. Marshall and P. S. Millar, general secretary.

SECTION NOTES.

CHICAGO SECTION.

At a meeting of the Chicago section held March 21, Mr. M. Luckiesh, assistant physicist of the National Electric Lamp Asso-

ciation, Cleveland, read a paper entitled "The Influence of Spectral Character of Light on Effectiveness of Illumination." The paper with its attending discussion will appear in the April issue of the TRANSACTIONS.

"Window Lighting," by Mr. J. Henninger, is the subject for discussion at the meeting on April 18.

The titles of the papers to be presented at the May and June meetings have not yet been announced.

NEW YORK SECTION.

At the March meeting of this section Dr. H. E. Ives, of the National Electric Lamp Association, read a paper on "The Application of Photography to Photometric Problems." The paper appears in this issue of the TRANSACTIONS. Mr. J. A. Sawyer, of the Cinemacolor Company, gave an interesting talk on the use of light in producing motion pictures in natural colors. Mr. Sawyer supplemented his remarks with several series of pictures depicting life in several foreign countries. About 230 members and guests were present at the meeting.

On May 2 the New York section will hold a joint meeting with the New York chapter of the American Institute of Architects. A paper entitled "The Relation of Light to Shadow and Color in Design" will be presented by Messrs. Bassett Jones, Jr., and Henry Hornbostel. The paper will be supplemented with models and color booths. Preceding the meeting there will be a dinner at Keene's Chop House, 70 West 36th St., New York.

PHILADELPHIA SECTION.

At the meeting of the Philadelphia section held March 15, Dr. H. E. Ives read a paper on "The Application of Photography to Photometric Problems" which was read before the New York section on the 14th. Prof. A. J. Rowland gave his third talk on Essential Principles of Illumination entitled "Shades and Redistribution of Light." Dr. C. H. Sharp also gave a talk on "Casual Observation of European Lighting."

At the meeting scheduled for Friday evening, April 19, at eight o' clock, Mr. Elias Goldensky will read a paper on "Arti-

ficial Illumination in Portrait Photography." Prof. A. J. Rowland will also give the fourth of his series of talks on the Essential Principles of Illumination. The members of Professional Photographic Association have been invited to attend this meeting. As usual a dinner will precede the meeting.

PITTSBURG SECTION.

The following program for meetings of this section has been announced:

April 12—"Gas, Gasoline, Arc and Incandescent Street Lighting" by Mr. H. H. Magdsick of the National Electric Lamp Association of Cleveland.

For the May meeting—a paper on semi-indirect lighting.

NEW ENGLAND SECTION.

The New England section held a meeting March 25, at which Mr. Norman Macbeth read a paper on "Competitive Illuminants from the Standpoint of the Salesman."

At the meeting to be held April 29, Mr. Edward W. Burdett, chief counsel of the Edison Electric Illuminating Company of Boston will read a paper which will deal with competition in a community already served properly by a public utility company that involves economic loss.

The papers for the May and June meetings will be announced later.

NOTICE.

The chairman of the papers committee, Mr. Bassett Jones, Jr., 1 Madison Avenue, New York, invites suggestions from the members of the society as to the character of papers that should be presented at the annual convention of the society which will be held at Niagara Falls, Can., in September. He will be grateful for any information suggesting titles of papers together with the names and addresses of authors from whom such papers might be obtained. His committee is endeavoring to arrange a program of papers which both in excellence and originality will surpass the program of any previous convention of the society.

JOINT MEETING OF WASHINGTON ARCHITECTURAL CLUB AND I. E. S.

A joint meeting of the Washington Architectural Club and the Illuminating Engineering Society was held in the hall of the Cosmos Club, Washington, Tuesday evening, March 12. Mr. V. R. Lansingh, president of the society, gave a lecture on some of the general principles of interior illumination. Mr. A. L. Harris of the firm of Hornblower & Marshall, architects, in Washington, read a paper on Interior Lighting and Lighting Fixtures. About 250 members of the club and the society attended the meeting.

A. I. E. E. - I. E. S. MEETING IN BOSTON

Arrangements have been made for a joint meeting of the American Institute of Electrical Engineers and the Illuminating Engineering Society during the annual convention of the former organization in Boston next June. Three papers on illuminating engineering subjects will be read by members of the society: one on interior lighting by Bassett Jones, Jr.; a second on the relation of illuminating engineering to electrical engineering, by Dr. Louis Bell; and a third on color by Dr. H. E. Ives. Dr. Ives' paper will be supplemented by a number of experimental demonstrations.

THE APPLICATION OF PHOTOGRAPHY TO PHOTOMETRIC PROBLEMS.*

BY HERBERT E. IVES.

Photometry has been indispensable in unraveling the laws of photography. Now that these laws are well known, the possibility of using photography as an aid to photometry is becoming evident. Occasions frequently arise where the peculiar properties of the photographic process make it available for photometric investigations which otherwise would be extremely difficult, or even impossible. It therefore becomes important to the photometrist to know the characteristic properties of the photographic plate and the laws of photographic action, in so far as they assist or limit the plate's availability for photometric measurements. In this paper are gathered together certain facts about photography which must be kept in mind in applying photography to photometry, following which are outlined some applications which have been made, and some suggestions of other fields in which photography might be of assistance in light measurement.

In advance let it be stated that there is little object in attempting to use photography in the ordinary simple operations of photometry, such, for instance, as the measurement of candle-power on a photometer bench. The relatively complicated and time-consuming processes of exposure, development, and final photometric measurement of the sensitive plate would make it absurd to substitute the latter for the eye unless some other method of measuring photographic density than the photometric one proves more sensitive. Only in those cases where the camera can do what the eye cannot should photography be considered. These may be practically confined to faint or transient phenomena. The photographic plate possesses two valuable properties: one, it integrates faint or brief stimuli; two, it records simultaneously actions which are extended in space. The importance of these properties may be illustrated by citing the use of photography in astronomy. On a single plate hundreds of stars may be photographed simultaneously for future measurement; and, by pro-

* A paper read before the New York section of the Illuminating Engineering Society, March 14, 1912, and the Philadelphia section, March 15, 1912.

longed exposure, stars may be detected too faint to be seen by the eye. Thus, two limitations of the eye—its inability to fix upon more than one point at a time, and its insensitiveness to faint light—are overcome by the sensitive plate. Other cases are the use of photography to record the appearance of the sun and its surroundings during the brief seconds of an eclipse, and the accurate recording of meteor trails whose short careers defy mapping by the unaided eye. Some illustrations nearer home are the study of the character of the firefly's intermittent light by means of photography; the distribution of light in an extended landscape, and the distribution of light about a fluctuating source. These are, however, reviewed in detail below.

In order to use the photographic plate (or any other instrument) for photometry, it is essential to know the relationship between the intensity of the acting light and the resultant action. In the photographic plate the relation is that between intensity of light and opacity of plate; and, since time of exposure and intensity of light are partially interchangeable, exposure time must also be considered.

For the laws of the photographic plate we are indebted to Abney, Hurter and Driffield, and others. They have studied the plate principally with regard to its perfection for pictorial purposes. While from the standpoint of photometry it is not necessary that a photograph look like the original, so long as its laws are known, it is nevertheless convenient to study the problem from the usual standpoint.

For the sake of simplicity let it be assumed that the original object photographed is a photographic transparency. The ideal negative is one whose gradations are exactly complementary to the original. If this negative is laid upon the original transparency, the transmission of the two together will be everywhere the same; that is, the picture will be completely obliterated. If t and t' are the transmission of the positive and negative at any point, the condition just stated is that

$$t.t' = c,$$

where c is the minimum transmission of either plate and may be quite small although not zero.

The following quantities are used in the discussion of the photographic plate:

$$\text{Transparency, T} = \frac{\text{transmitted light}}{\text{incident light}} = \frac{J_t}{J_i}.$$

$$\text{Opacity, S} = \frac{1}{T} = \frac{J_i}{J_t}.$$

$$\text{Density, D} = \text{log. opacity} = \text{log.} \frac{J_i}{J_t}.$$

Density as thus defined, in accordance with the law of absorption, measures the actual quantity of deposited material in the plate.

To determine the relations between these quantities in order that the plate may be of the ideal character specified, let t be replaced by i, the intensity of the light acting on the plate during the exposure, then

$$it' = c \text{ or } i \frac{J_t}{J_i} = c,$$

taking logarithms,

$$\text{log. } i - \text{log. } c = \text{D}.$$

Hence in the ideal negative if density (D) is plotted against

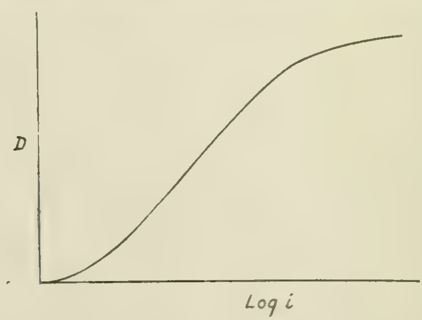

Fig. 1.—Relation between intensity of incident light and resultant photographic density.

the logarithm of the acting intensity of light, a straight line at 45 deg. results. Actual measurements of the density of exposed plates shows the relationship exhibited in fig 1. This may be analyzed as of three parts: an initial period during which the growth of density with increasing intensity of exposure is very slow (under exposure); an intermediate period where growth of density is faster, and where it plots approximately as a straight line (correct exposure); a final period where the increase of in-

tensity causes little increase of density (over exposure). The intermediate portion is found to be represented by the equation.

$$\gamma\ (\log.\ i - \mathrm{K}) = \mathrm{D}.$$

The term within the brackets appears to be, with certain limitations, a function of the plate and the exposure: the term γ is the "development factor." That is, by proper development, γ may approximate unity, and the negative in its intermediate position approximate the ideal negative. The effect of different developments, that is, values of γ, is shown in fig. 2. Here the

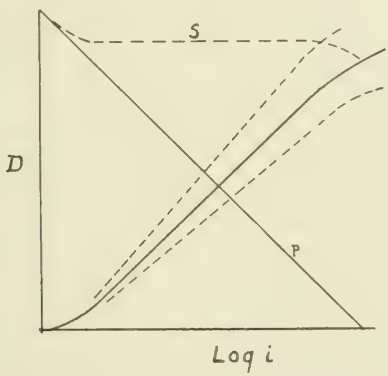

Fig. 2.—An illustration of the effect of different photographic developments.

straight line p represents the density of the original positive. The negative is perfect when the summation of the density of negative and positive is a constant (S). It is readily seen that this may be controlled by the development, provided the negative conforms to the relation above. Furthermore, by under or over development, intensity differences in the original may be represented by smaller or larger transmission differences in the negative. If, however, the exposure is such that the portion represented by this relation does not fall in the range of intensities it is desired to represent, no process of development will save the negative.

Thus far in the discussion only the relation between density and intensity has been considered, on the assumption that the time of exposure is constant. A similar relation holds between

density and time of exposure when incident intensity is maintained constant. Thus, the case just considered may be written:

$D_i = \log. (K_1 i)^m$ (t constant) (which holds for a given development). We also have $D_t = \log. (K_2 t)^n$ (I constant), where t is the time.

Combining these

$$D = \log. (K_1 i)^m (K_2 t)^n.$$

For any two densities on an exposed plate we have

$$D_2 - D_1 = \log. \left(\frac{i_2}{i_1}\right)^m \left(\frac{t_2}{t_1}\right)^n.$$

Hence, knowing m and n it is possible by measuring the densities to determine $\frac{i_2}{i_1}$, if $\frac{t_2}{t_1}$ is known, or vice versa. If t is constant or $\frac{t_2}{t_1} = 1$, this reduces to

$$e^{\frac{D_2 - D_1}{m}} = \frac{i_2}{i_1}.$$

This relationship only holds in the intermediate normal exposure region as defined above. It is therefore necessary to know between what range of intensities this region lies, and what the differences of intensity are in terms of differences in density. This amounts to studying the *range of gradation* of the negative.

The range of gradation of a plate may be long or short, depending upon several physical factors to be discussed later. The difference between a long and a short scale of gradation is well shown by measurements on a single thickness of film and of half a dozen films exposed one behind another (taken from Abney) fig. 3.

Curve A is for the thin layer of sensitive material, B for the thick layer. It is readily seen that in the latter case the region approximately represented by a straight line $a''c''$ may be two or three times as long as in the former ($a' b'$).

Several consequences of this behavior of the thinly coated plate are important. First, it is to be noticed that on such a plate, having a short scale of gradation, the range of intensities corresponding to measurable differences of density may be quite short, say 20 or 30 to 1, and the region where the simple law

holds which connects density and intensity may be even shorter. Second, by proper choice of exposure the interval of good gradation may be made to fall on any desired part of the gradation of

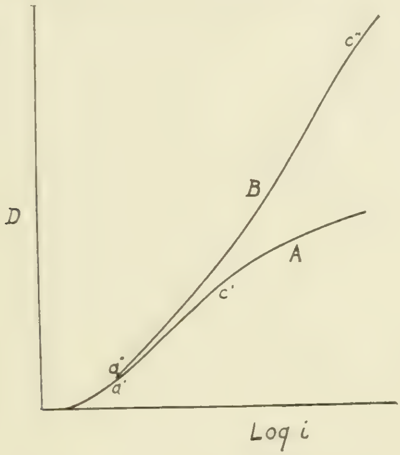

Fig. 3.—Long and short scale of gradation.

the object, but not on all. For this reason a plate with a long scale of gradation has a wide latitude of exposure. For instance, if it is desired to photograph a range of intensities of 1 : 30, there is three times the latitude of exposure on a plate which

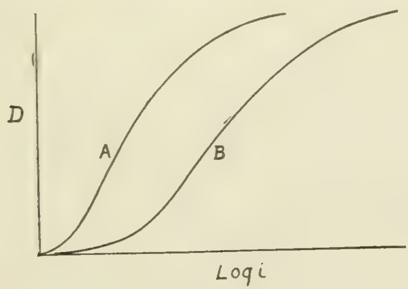

Fig. 4.—Long and short exposures.

plots as a straight line over a range of gradation of 1 : 100, as on one having only a range of 1 : 30. Figure 4 shows the effects of different exposures. This exhibits what is well known to photographers, that with a fast plate (which has a small range

of gradation) one may either secure detail in the shadows (A) at the expense of losing detail in the high-lights, or secure detail in the high-lights at the loss of detail in the shadows (B).

Another peculiarity of the photographic process which has been mentioned above may here be repeated. By long development (large γ) the whole range of densities in the plate may be made to correspond to a small range of incident intensities. By using this fact small differences of intensity may be magnified by repeating the photographic operation several times. A difference of brightness below the limit of visual sensibility may be detected in this way.

Keeping in mind the various facts which have been reviewed it is possible, by measurement of an exposed and developed plate, to determine whether the exposure is such as to use the best part of the gradation scale, and to determine at once whether a plate is under-exposed or merely under-developed. The experienced photographer makes these decisions by mere inspection, but in accurate work actual measurements are helpful and indeed indispensable.

In how far one may use the relationship between intensity and density, and over what range measurable differences in density correspond to finite intensity differences (the latter of course somewhat larger than the former) are naturally the important questions in photographic photometry. A range in intensity of 30 to 1 is small, of 100 to 1 none too large. By proper choice of plates of long scale of gradation the latter figure is possible. It is, however, important to know what means if any are available for increasing this range.

There is as a matter of fact just one means, viz., variation of the time of exposure. For a long time it was believed that intensity and length of exposure were interchangeable, or

$$i \times t = \text{constant}.$$

Were this so it would only be necessary to know the ratio of the exposures of two points of equal density on a plate to know the relative intensities of the original illuminations. It was found a few years ago, in astronomical photography, that long exposures did not reveal as small magnitude stars as was to be expected from this law. Study of the problem by Schwartzchild

led to the formulation of the Schwartzchild law, namely, that for points of equal density on a plate

$$It^p = iT^p,$$

where I and i are the larger and smaller intensities, T and t the larger and smaller exposure times. The value of p varies according to the plate, and it appears, according to the color of the light; generally it lies between 0.75 and 1.00. It is also questionable whether it holds outside the range of normal exposure.

The question of the integration of intermittent or fluctuating illuminations is an important one, and is partly dependent for its discussion on what has gone before. One of the most important properties of a photographic plate is its power of adding faint stimuli. According to what law is this addition? For continuous faint illumination the laws already discussed give the answer. For intermittent stimuli the answer is not clear. Certain researches have indicated that a succession of half-time impulses give greater density than a continuous exposure of half intensity. This would be in direct accordance with the Schwartzchild law; for let $I = 2i$, then

$$2it^p = iT^p,$$

or

$$\frac{T}{t} = 2^{\frac{1}{p}},$$

or the relative exposures to give the same density are in a ratio to each other greater than that of the intensities. Of course, in a plate where $p = 1$ there is a complete equivalence of time and intensity.

It is probable that the integrating effect of a plate with intermittent light is different depending on whether the separate flashes of light lie in the region of under-exposure or of normal exposure. Differences too occur depending on the ratio of the duration of the flashes of light to the interval between flashes. In every case where it is desired to use photography with fluctuating or intermittent illumination actual experiments should be made under similar but controlled conditions to determine the approximation to true integration. In general, however, it

is to be expected that a fluctuating light will be recorded as of greater intensity than its true mean value.

THE PHYSICAL CHARACTERISTICS OF THE PHOTOGRAPHIC PLATE.

In order to understand some of the limitations of the photographic plate and some precautions to be observed in its use, a review of the chief physical characteristics of the plate is necessary, together with a glance at the technique of development and measurement.

The ordinary photographic plate consists of a film of gelatine on glass. The gelatine, before flowing upon the glass, has had deposited in it silver bromide, which is the sensitive substance. Depending upon the temperature of preparation the granules of silver bromide will be coarse or fine; in the former case the emulsion will be fast, in the latter slow. If the coating is thick the gradation of the plate will be longer than if the coating is thin.

For ordinary photography the emulsion is flowed on common sheet glass. To insure a uniform thickness of emulsion plates intended for photometric work should be upon plate glass.

The untreated emulsion is most sensitive to blue, violet, and ultra-violet light, and very insensitive to yellow and red. By the use of certain dyes, called sensitizers, it is possible to make silver bromide sensitive to color. These dyes may be employed in either of two ways; first, by incorporation in the emulsion during preparation; second, by the process of bathing the finished plate in a dilute solution of the dye. In the former case the sensitizer is distributed comparatively uniformly through the depth of the film; while in the latter case it is confined more to the surface. Different emulsions may be expected to differ slightly in their relative sensitiveness to different colors, depending upon the degree to which the different sensitizers have acted.

Different types of developers have different characteristics. Some like pyrogallic acid act chiefly upon the surface of the plate; others like hydrochinone act throughout the depth of the sensitive layer. In working with color-sensitive plates, development in total darkness is necessary; in all cases it is advisable. By trial determination of the development factor it is possible to arrive at the correct time of development at a given temperature.

Thereafter, by carrying on development always at one temperature, with fresh developer, for a definite time, the highest possible uniformity of results is attained.

The density of the developed plate may be measured in any photometer having a field of suitable dimensions; photometers of the polarization form are very convenient; a thermopyle and galvanometer are in some cases advantageous. Because of the scattering power of the deposited silver in the film the apparent density is different at different distances from the plate. This peculiarity makes it essential that the comparison exposure patches be measured under the same conditions as the test areas. The absorption may be measured either against the absorption of an unexposed area of film, or against the absorption of clear glass, while again the absorption of glass, film and deposited silver may be measured together. The two former, since they enter mainly as multiplying factors, do not affect the slope of the plot of density against intensity. In measuring plates actual densities may be plotted against intensities, though frequently it is sufficient to plot intensities against the readings of the measuring instrument, be they angles or distances.

VARIATIONS IN PHOTOGRAPHIC LAWS DUE TO PHYSICAL PECULIARITIES OF THE PLATE.

The influence of film thickness and the size of the grain of the plate on speed have been mentioned. One other phenomenon is of particular importance to photographic photometry. Under certain conditions it is possible for the plate to exhibit a well marked Purkinje effect, or the reverse of that effect. Ordinarily the color of the sensitive emulsion is yellow, consequently it is more transparent to orange and yellow than to blue light. Because of this the effective thickness of film is less for blue light than for yellow, orange or red; consequently the range of gradation is less. Also the development factor is smaller for the same exposure, since the developer does not increase the quantity of reduced silver by penetration into the film as it does for a thick film. Due to the latter cause, chiefly, it happens that with an orthochromatic plate, in which the color sensitizers are mixed in the emulsion, the gradation is steeper for red

than for blue light. On the other hand, if the plate is made sensitive to color by bathing, the color sensitive layer may be so thin as to make the blue gradation the steeper. In the first case the

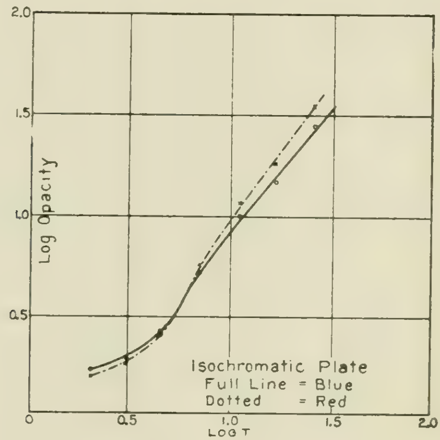

Fig. 5.—Purkinje effect.

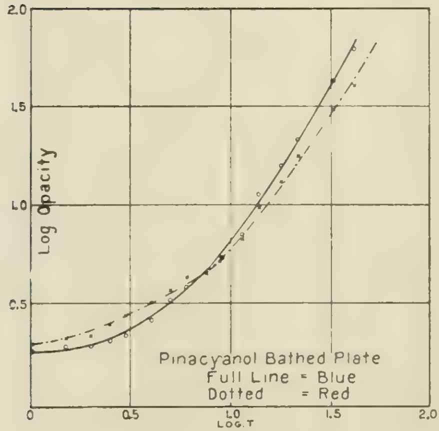

Fig. 6.—Reversed Purkinje effect.

plate shows a Purkinje effect; in the second, the reverse of that effect. These are exhibited in figs. 5 and 6.[1]

[1] H. E. Ives, Photographic Phenomena Bearing upon Dispersion of Light in Space, *Astrophysical Journal*, March, 1910.

Another peculiarity of the photographic film,—chemical rather than physical—is its different behavior according as development is immediate or deferred. If two equal exposures are made successively upon the same plate and the plate is developed immediately after the second exposures, the two densities will not be the same. To avoid errors due to this cause both the test and comparison exposures should be made at the same time, or else development should be deferred for such a period—a day, for instance,—that the interval between the exposures becomes a negligible part of the total delay.

A TYPICAL PROCEDURE.

The method of applying photography to problems in photometry may be most clearly presented by outlining a typical procedure. Suppose that one wishes to measure by photography the distribution of brightness over a certain surface called in this instance the test surface. There should be prepared a set of patches of known brightness which one may call comparison patches, and whose range shall be somewhat larger than the range of brightness on the test surface. The test surface and the comparison patches are to be photographed together and developed together. Should the range of brightness be greater than the range of gradation that the plate will render successfully, several photographs of different exposures should be made. When the negatives are developed for such a time as will give a development factor of unity or perhaps slightly more, they are to be measured for density. A plot connecting intensity and density is obtained from the comparison patches. From the measured densities of the test surface photograph its intensity or brightness distribution may be determined.

SOME APPLICATIONS.

A few applications may here be touched upon by way of illustration. A prominent scientific application is in spectrophotometry. In cases where the available quantity of light is small, photography makes spectrophotometry possible with narrow slits and consequently with greater accuracy than with the eye. A unique possibility of the photographic method is the measurement of

ultra-violet spectra, to which the eye is not sensitive. It has been used for instance in testing the Wien-Planck radiation law in that spectral region. Fluctuating sources and sources with complicated spectra are those to which photography is peculiarly applicable. For instance, the measurement of the distribution of light in the spectrum of a flaming arc, where spectral lines, bands and continuous background are all present together is probably almost impossible by other than photographic methods. The determination of the spectrum of such a faint and intermit-

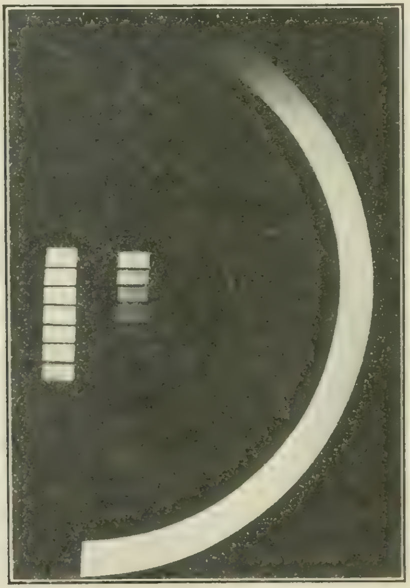

Fig. 7.—Photographic determination of candle-power distribution curve.

tent source as the firefly,[2] practically impossible to determine visually, has been made possible by the use of photography. In the cases just mentioned there are of course outstanding uncertainties due to the fact that the laws of summation of irregular flashes of light are somewhat in doubt. But by closely paralleling the character of the source under test by the comparison exposures these outstanding second-order differences may be minimized.

[2] H. E. Ives and W. W. Coblentz, The Light of the Firefly, *Trans. Illum. Eng. Soc.*, Oct., 1909.

Photography lends itself to the determination of the distribution of illumination. The distribution of illumination around an arc light, for instance, may be registered by photographing an annular strip of diffusely reflecting material illuminating by the arc at its center. Thus, the mean distribution holding during the exposure may be obtained, or a favorable steady moment may be chosen for the exposure. The writer and Mr. Luckiesh are at the present time working upon this scheme, which promises to reduce greatly the labor involved in determining arc lamp distribution curves. Fig. 7 shows such a photograph, with the comparison intensities of known value in the center for reference. If it is found possible to obtain a plate for which the exponent p in the Schwartzchild law is unity it will also be possible to obtain actual mean candle-power values. But even with a value nearer 0.8 the error in the integration is probably not greater than 5 per cent. and always in one direction. Another opportunity for photographic determination of illumination distribution is in studying extended landscapes.[3]

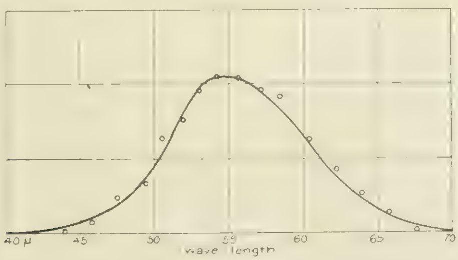

Fig. 8.—Performance of a visual color filter.

In order to obtain the true visual distribution in the case just considered and in similar cases it is essential that the plate shall have the same distribution of color sensitiveness as the eye. This may be accomplished by careful choice of absorbing screens to fit the kind of plate used. The performance of such a screen, composed of tartrazine, rhodamine, naphthol green, and aesculine, used with a Cramer spectrum plate, is shown in fig. 8. When obtained, such a screen makes possible the photometry of lights of different colors, with the difficulty of comparing different colors in the visual work removed. Except for com-

[3] H. E. Ives and M. Luckiesh, The Distribution of Luminosity in Nature, *Trans. Illum. Eng. Soc.*, Oct., 1911.

paratively rough work, however, the substitution of the photographic plate for the eye with a view to avoiding the difficulties of heterochromatic photometry is not to be seriously recommended.

A last suggestion of a possible use of photography in photometry is the measurement of color. The three negatives necessary for carrying out the three-color process of color photography contain in their relative densities a record of the color of the object. In some cases where a unique record of color is desired and where exact correspondence with visual values is not the first essential photography might be exceedingly useful. One such case is in the measurement of star colors, a problem which at present is sadly confused by physiological variables.

NATURAL GAS; ITS PRODUCTION AND UTILIZATION.*

BY GEORGE S. BARROWS.

Natural gas belongs to that group of natural products of the earth known as bitumens. Other members of this same group are fluid petroleum, semi-fluid maltha and solid asphaltum. All these products have a similar general history and are found under similar conditions, and transitions from one to another may be often noted. Technically they are known as hydrocarbons, their constitution generally being hydrogen about 13 per cent. and carbon about 85 per cent. Their utilization antedates history, but their technical and commercial importance to the civilized world is of quite recent date, or within, say, the last fifty years.

While natural gas is known, and to some extent made use of in nearly every country of the world, its production on a large scale is confined principally to this country, and here the main producing areas are in the northern parts of the Mississippi and Ohio River valleys, the mid-continental area in Kansas and Oklahoma, and in southern California; though in many states outside of these areas there has been or is a considerable production.

The main supply of the gas is, in the Appalachian field, from the Devonian to the upper coal measures. In northwestern Ohio and Indiana it emanates from the Trenton limestones or the Clinton limestones, and in Kansas and Oklahoma from the sandstones of the coal measures immediately above the Mississippi limestones.

The theories as to the origin of natural gas may be divided into two groups: (1) those which assume it is the product of an inorganic source as the result of chemical action on mineral matter, and (2) those which assume it is the result of a partial decomposition of animal or vegetable substances.

Of the inorganic theory there are two notable examples: first, that the alkaline metals exist in the interior of the earth in a free or uncombined state, and necessarily at a high temperature. If

* An abstract of a paper read by George S. Barrows at the fifth annual convention of the Illuminating Engineering Society, Chicago, Sept. 25-28, 1911.

now, water, carrying in solution carbonic acid finds access to these metals the result would be the formation of a series of hydrocarbon compounds. Second, the interior of the earth may be supposed to contain large masses of metallic iron and metallic carbides, all at high temperature. Water in contact with such substances under these conditions would generate metallic oxides and hydrocarbons.

To the theory of organic origin there are also two general groups of adherents. One supposes that natural gas is produced from the primary decomposition of organic matter in the rocks containing such matter; for it is well known that the decomposition of such substances in the absence of air will form products similar to natural gas. The other assumes a secondary decomposition of the organic matter stored in the rocks, that is, the animal and vegetable matters have suffered a partial transformation and are now held in the rocks as hydrocarbon compounds and from these, by a process of distillation, the gas is derived.

The gas is stored in porous rocks such as sandstone or limestone with an impervious covering of shale or similar rock. These reservoirs of rock are at varying depths ranging from a few hundred to several thousand feet below the surface, but the gas is always in a porous rock overlaid with a non-porous covering.

While in many cases, in the same field these reservoirs may exist in lenticular form, it is usual for the various portions of the same field to be more or less in communication with each other, so that wells in one part of the field are more or less affected by the output of wells in other parts; but in no case can there be any large accumulation without the approximately impervious roof.

The disturbances of the strata have no little effect on the location of productive wells for it seems certain that the best wells are usually along the crests of the anticlinal folds, though many large wells have been found in or near the centers of synclines, where, however, there may be subordinate or secondary anticlinals.

The cause of the high pressure (usually many hundred and frequently several thousand pounds) is another source of specu-

lation. One explanation is that the gas is capable of occupying a vastly greater space than that occupied by the materials from which it was derived; another is, the weight of the superincumbent rocks, but this one is of doubtful value for it could only be true if there were freedom of motion throughout the rock. A third explanation is that the hydrostatic pressure of the water always found near gas wells causes a head pressure of the gas in the traps formed by the anticlinals. This is the generally accepted theory and pressure conditions found in wells in various parts of the country seem to warrant its approval.

Different wells, even in the same field, show different analyses, but as a rule the characteristics of a field apply to all its wells, though there may be variations. The following table gives representative analyses of gas from the principal fields:

	Ohio	Indiana	Pennsylvania	Kansas
Carbonic oxide, CO......	.55	.73	.00	.33
Hydrogen, H_2	1.89	1.86	.02	.00
Methane, CH_4............	92.84	93.07	95.42	95.28
Ethylene series, C_2H_4, etc.	.20	.47	.00	.67
Carbonic acid, CO_2.......	.20	.26	.05	.44
Oxygen, O_2	.35	.42	Trace	Trace
Nitrogen, N_2	3.82	3.02	4.51	3.28
Hydrogen sulphide, H_2S..	.15	.15	——	——

Ohio	B. t. u. per cu. ft.	....	948.15	(calculated)
Indiana	" "	....	922.62	"
Pennsylvania	" "	....	1252.00	"
Kansas	" "	....	973.08	"

A peculiar variation is the presence in some wells of large proportions of nitrogen as in:

	Princeton, Ill.	Dexter, Kan.
Carbon dioxid	0.10	0.00
Carbon monoxid	0.05	0.00
Oxygen	0.05	0.20
Methane	13.97	15.02
Nitrogen	85.83	71.89
Hydrogen	——	0.80
Inert media	——	12.09
	100.00	100.00

Broadly speaking, the drilling rig and tools for drilling gas wells are similar to those used for any driven well, though because

of the great depths to which they are sunk the equipment is rather heavier and the tools more elaborate. Proper precautions must always be taken to prevent the caving of the sides of the well and the seepage of water to the gas chamber at the bottom. This is done by "casing" or inserting in the hole from the top to near the bottom, iron pipe of lighter weight than the gas conveying pipe which extends from the top to the bottom on the axis of the well. A gasket or washer called a "packer," inserted near the bottom, surrounds the gas pipe and extends to the periphery of the hole making a chamber for the gas which is collected here and taken to the surface by means of the central pipe.

From the top of the well the gas is led by a suitable pipe to the point of utilization. The pipe used is generally of wrought iron or steel; the small sizes are made up with screwed joints and the larger ones with some kind of coupling. The coupling generally used consists of a "center ring" which slips over the ends of the pipe to be joined, and a gasket of rubber at either end of this ring, the gasket being held tightly to the "center ring" by "follower rings" suitably drawn together by means of bolts. This makes a tight and strong but at the same time more or less flexible joint. The pipe is usually laid about thirty inches below the surface of the ground.

When crossing a stream a coffer dam may be built and the pipe laid in a trench in the bottom of the stream. If the stream be too wide or deep to conveniently build such a coffer dam, the pipe may be made up on shore and then hauled across and sunk. In any case, a number of small pipes, connected into a header on either side, are used in preference to one large pipe, both for the purpose of giving stability to the line and to ensure a more certain supply in case of possible accident to the subaqueous line.

If the line is of considerable length, and the consumption is large or the well pressure low, it may be necessary to augment the well pressure. This is done by means of compressors, operated by any convenient means but usually by direct acting gas engines, which receive their fuel supply from the gas line itself. On long lines several such compressing stations may be necessary, for the friction loss in the pipe is large. Such long

lines are: to Cleveland from West Virginia, about 120 miles of 18″ and 12″ pipe with a daily capacity of 83,000,000 cu. ft.; to Cincinnati from West Virginia about 150 miles of 18″ and 20″ pipe with a daily capacity of 70,000,000 cu. ft.; to Kansas City and other cities in northeastern Kansas and northwestern Missouri from Oklahoma, about 250 miles of two 16″ pipes with a daily capacity of 90,000,000 cu. ft. All these lines have, at intervals, compressing stations of gas driven pumps. Some of the stations have a total capacity of over 10,000 horse-power.

The usual formula for the flow of natural gas is that of Pole as modified by Prof. Robinson:

$$Q = 48.4 \sqrt{\frac{T_1}{T_2 T_0}} \sqrt{\frac{d^5}{L}(P_1 + P_2)(P_1 - P_2)} \sqrt{\frac{0.6}{g}},$$

Q = cubic feet delivered per hour.

P_1 = absolute initial pressure in lbs. per sq. inch.

P_2 = absolute terminal pressure in lbs. per sq. inch.

d = diameter of pipe in inches.

L = length of pipe in miles.

T_0 = absolute temperature at maximum density of water $461 + 37 = 498°$ F.

T_1 = absolute temperature of gas after delivery.

T_2 = absolute temperature of gas flowing in main.

g = specific gravity; air = 1. To correct formulas for other specific gravity than that given, multiply result by:

$$\sqrt{\frac{g \text{ in formula}}{g \text{ of other gas}}}.$$

As the gas pressure in the main line is very high, sometimes reaching over 200 pounds, it would be impractical to distribute the gas at such a pressure in a city or town. It is therefore customary, at a point near the city line, to install a governor or regulator to reduce this pressure to one suitable for distribution in the city. The regulators are usually of the common diaphragm type. The pressure is reduced to either a few ounces, or the house pressure, or to a few pounds, at which pressure it is supplied through an intermediate main to various sub-reducing stations where it is again reduced to the house pressure. Or the gas may be distributed at a few pounds pressure and individual governors used, one being placed on each house service pipe.

For domestic purposes natural gas is used in the same way

and with the same appliances as manufactured gas, though owing to its low candle-power it is seldom used for light with the open flame burner. With the incandescent mantle, however, it proves a most satisfactory illuminant.

Besides these uses, great quantities of natural gas are used as fuel for house heating, being burned in the fire-pots of hot air furnaces, hot water and steam boilers and in heating stoves as a substitute for coal, and its convenience and cleanliness make it most popular for these purposes.

For industrial purposes it is used as a substitute for coal or oil, in the smallest as well as the largest appliances, from the laundry water heater and china kiln to a high pressure steam boiler of many hundred horse-power and the large brick kiln of many arches.

It is used directly for the manufacture of carbon black and recently there have been many attempts at the production of gasoline by compression.

Because of its cheapness and relative ease of production there has always been great waste of natural gas. It is estimated that in West Virginia alone, as much as 500,000,000 cubic feet daily have been lost for a long period of years. Measures are now being taken by many states to so control the methods of production and utilization that this waste will be reduced or eliminated.

To give some idea of the immensity of the industry a few figures may be quoted from the United States geological reports.

In 1882 the approximate value of the natural gas produced was	$ 215,000
In 1890 the approximate value of the natural gas produced was	18,792,725
In 1900 the approximate value of the natural gas produced was	23,698,674
In 1909 the approximate value of the natural gas produced was	63,206,941

In 1909 the approximate distribution of the gas was as follows:

Producers	8,119
Consumers, domestic	1,223,438
Consumers, industrial	17,259
Gas consumed, domestic, cu. ft.	151,222,223,000
Gas consumed, industrial, cu. ft.	329,483,951,000
Average price for thousand cu. ft., domestic	24.23 cts.
Average price for thousand cu. ft., industrial	8.06 cts.

During 1909, 3705 wells were drilled of which 778 were dry, leaving 2927 productive. The total number of productive wells at the end of 1909 was 24,184 on a lease acreage of 8,746,982 acres.

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TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. APRIL, 1912. NO. 4

COUNCIL NOTES.

The council held a meeting in the general office of the society, April 12. Those in attendance were V. R. Lansingh, president; C. J. Russell, W. J. Serrill, treasurer; J. T. Maxwell, L. B. Marks, Norman Macbeth, J. R. Cravath and Albert J. Marshall.

A monthly report on the society's accounts and membership was received from the assistant secretary. According to this report the expenses of the society for the first three months of 1912 had totaled $2,647.67; the total membership, exclusive of the applications and resignations on hand was given as 1469.

Fourteen applicants were elected to membership. One application for reinstatement was accepted. Four resignations were accepted. The names of seven members were dropped in default of dues. Counting these changes there were 1473 members on the membership roll of the society.

In accordance with a recommendation contained in a report of the finance committee, payment of March bills amounting to $699.97 was authorized.

Niagara Falls, Can., was selected as the place for the 1912 convention of the society. The time will be announced later. Mr. Norman Macbeth was appointed chairman of the convention committee.

Progress reports were received from the following committees: financial policy, advertising, reciprocal relation with other societies, new membership, and nomenclature and standards.

Oral reports were heard on behalf of the papers and editing committees.

The committes on illumination primer reported that the work of preparing the primer was nearing completion.

SECTION NOTES.

CHICAGO SECTION.

At a meeting of the Chicago section held April 18, Mr. J. Henninger of the National Electric Lamp Association, Cleveland, read a paper entitled "Window Lighting'.'

The title of the paper to be presented at the May meeting on the 16th proximo has not yet been announced.

NEW YORK SECTION.

Two papers were read at the New York section meeting on April 11, one "A Laboratory System for Testing Electric Incandescent Lamps" by Mr. W. M. Skiff of the engineering department of the National Electric Lamp Association; the other "The Lighting of Passenger Vessels" by Mr. L. C. Porter of the General Electric Company. The latter paper appears in this issue of the TRANSACTIONS.

On Thursday evening, May 2, the New York section will hold a joint meeting with New York chapter of the American Institute of Architects in the United Engineering Societies' Building, 29 West 39th Street, New York. A paper on "The Relation of Light to Shadow and Color in Design" will be presented by Messrs. Bassett Jones, Jr. and Henry Hornbostel. The paper will be supplemented with a number of models, color booths and demonstrations. Preceding the meeting there will be a dinner at Keene's Chop House, 70 West 36th Street, New York.

PHILADELPHIA SECTION.

More than 250 people attended the meeting of the Philadelphia section on the evening of March 19. Mr. Elias Goldensky presented an exceptionally interesting paper on "Artificial Illumination in Portrait Photography." Mr. Goldensky exhibited a quantity of rather ingenious apparatus which he uses in taking photographs entirely by artificial light. Several excellent specimens of color photographs taken by artificial light were also exhibited. The paper will appear in a subsequent issue of the TRANSACTIONS. A dinner which preceded the meeting was attended by about 120 members and guests.

The next meeting will be held May 17 in the auditorium of the Philadelphia Electric Company, 1,000 Chestnut Street, Philadelphia. Prof. A. J. Rowland of the Drexel Institute will lecture on the "Essential Principles of Illumination." Prof. Rowland will supplement his lecture with a series of experimental demonstrations. Previous talks on this subject by Prof. Rowland have created a great deal of interest among the members of the section. A large attendance is expected at the May meeting.

PITTSBURG SECTION.

The Pittsburg section held a meeting April 12. Mr. H. H. Magdsick read a paper entitled "Gas, Gasoline, Arc and Incandescent Street Lighting." The paper occasioned considerable interesting discussion. The meeting was well attended.

For the next meeting on May 17 a symposium on indirect lighting has been arranged. At least four papers on the subject will be read.

NEW ENGLAND SECTION.

At the meeting on the 29th instant, Mr. Edward W. Burdett, chief counsel of the Edison Electric Illuminating Company of Boston will read a paper dealing with the question of competition in a community which is properly served by a public utility company.

The titles of the papers for the May and June meeting have not yet been announced.

THE LIGHTING OF PASSENGER VESSELS.*

BY L. C. PORTER.

Last winter the writer had occasion to make an investigation of the practise then in vogue in the lighting of passenger vessels. The object of this investigation was to find out how the various ships were lighted, and to determine whether or not improvements could be made which would warrant the expense involved in making a change. To accomplish this object, a careful study of a large number of ferry boats, coastwise ships, river steamers, and transatlantic liners was made. Illumination measurements were taken on many of the boats. As a result of the tests made, several of the steamship companies are arranging to equip their boats with drawn-wire tungsten filament lamps, in place of the carbon lamps previously used.

It is the author's desire to give in this paper a general outline of the lighting conditions found on the various classes of ships, and suggest improvements which might be made.

In many instances it is impractical to change the existing wiring of a ship and, for this reason, the recommendations for a new ship would vary considerably from those for a ship at present in commission. When the wiring is already installed, the expense involved in changing the outlets may more than offset the advantage to be secured by a rearrangement of units to provide the most economical and effective service.

In all the cases here reported the outlets had been provided on the basis of using carbon incandescent lamps of 16 or 32-candle-power, or less. It was usually apparent that a better economy, and often a more effective illuminating effect, could be produced by the use of a smaller number of tungsten filament lamps of higher candle-power, but in every case it was considered unwise to change the existing outlets. However, advantage was taken of the higher efficiency of the tungsten filament lamp to increase the intensity, and, at the same time, reduce the lighting cost by substituting 25- and 40-watt tungsten filament lamps

* A paper read before the New York section of the Illuminating Engineering Society, April 11, 1912.

for the higher wattage carbon lamps, lamp for lamp. In some instances it was possible to also improve the diffusion by substituting frosted bulbs for clear ones.

From the lighting standpoint, passenger vessels may be divided into three classes: (a) boats on trips of less than one hour duration; this class is represented by ferry boats; (b) river, lake and coastwise steamers, with or without sleeping accommodations; (c) transatlantic steamers.

The requirements for which this investigation was made did not warrant a study of freight boats, pleasure yachts, and other craft not included in the above classification. Likewise, a study of the lighting of engine rooms, chart-houses, cafes, barber shops, freight holds, and other parts of the vessels, where the lighting was special and not typical of a large demand, was omitted.

FERRY BOATS.

Ferries, as common carriers, appeared in this country early in the seventeenth century. They are mentioned in the Colonial records of 1659. In volume three, of Stiles' "History of the City of Brooklyn" one reads: "Cornelius Dickerson, who had a farm on Long Island, came at the sound of a horn, which hung against a tree, and ferried the waiting passengers across in a skiff for the moderate charge of three stivers in wampum."

It soon became necessary for ferries to operate after dark. For this purpose candles, candle lanterns, and, subsequently, oil lamps were used for lighting the boats. That method of illumination prevails to-day on many of the small inland river ferries. Later, gas lamps, operated from tanks of compressed gas located on the decks, were installed. With the advent of the incandescent lamp, these gas systems were superseded by electric lamps.

Ferry boats are of two types: single and double deck. All boats examined were double-end and symmetrical, one-half being an exact duplicate of the other. Each type has, on the lower deck, passenger cabins on each side of the boat, with a compartment for wagons, automobiles, etc., between them. On each type of boat there is, on the main deck, one large cabin on each side, extending nearly the entire length of the boat; one, given over to smoking, and the other to women, and men who do not wish to

smoke. These cabins are practically rectangular in shape, their length being about 4.6 times their width. In the side-wheel boats these cabins are divided into two parts by the paddle box in the center—these parts are connected by a passage about 3 feet wide by 12 feet long. The cabin ceilings average 13 feet 6 inches in height. The seats in these cabins are generally arranged along the walls on each side. In some instances double benches, placed crosswise to the length of the cabin, are used. Frequently a combination of the two seating methods is used. The inboard

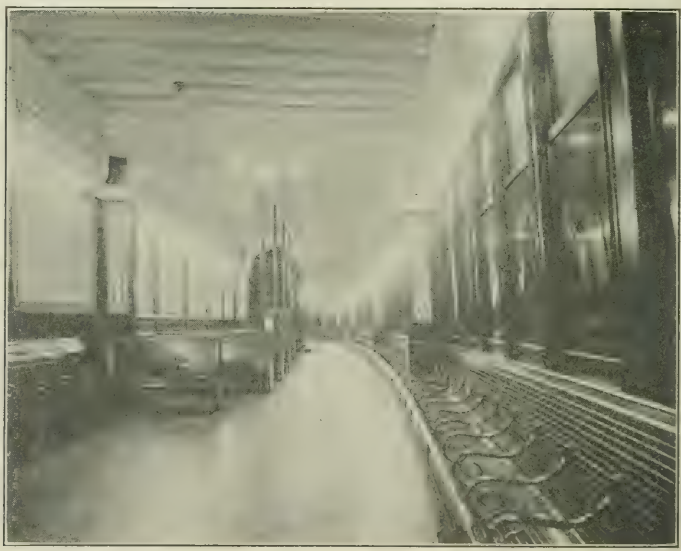


Fig. 1.—Typical lower cabin of a ferry-boat lighted with 40-watt tungsten lamps.

walls of these cabins are generally solid, while the outboard ones consist of a continuous row of windows, separated by one-foot casings.

The upper cabin, on the double deck boat, consists of one large room in the center of which is a rectangular compartment about 58 feet long by 9 feet wide, extending to the ceiling, through which pass the smoke stacks, etc. The ceilings in the upper cabins average about 9 feet 6 inches in height. Stairs lead down either at each end, or in the center of each side of the cabin. Seats are placed around the walls and against the smoke stack

compartment. In many instances benches at the ends of the cabin are used in conjunction with the wall seats. The outboard walls of these cabins also consist of a row of windows.

A general study of the lighting was made in all of the cabins, but more especial attention was given to the women's cabin on the lower deck of one particular double deck, screw driven ferry boat. In this cabin measurements of illumination were made with the old installation of 60-watt clear carbon incandescent lamps and later with a substitutional installation of 40-watt bowl-frosted, tungsten filament lamps. Each equipment was operated at its rated voltage. The results of these tests are shown as boats "E" and "F" in the table A.

It was found to be the general practise in both the lower and upper cabins to paint the walls medium color, and the ceilings either white or cream, thus giving the cabin a bright, cheerful effect, and also reflecting considerable light to the reader's paper. Lamps were installed in wall brackets over the seats, to the general exclusion of ceiling fixtures. In most cases the lamps were spaced evenly along the walls at an average height of about 9 feet above the floor. Most of the lamps were in simple, single-lamp fixtures and hung vertically, tip down. In a few instances the lamps were placed at angles of 45 degrees from the horizontal; in some cases two-lamp brackets were placed on the walls. Fifty and sixty-watt carbon lamps were in general use. Some boats were lighted by round bulb, all frosted, carbon and tantalum lamps. Frosted lamps were invariably used without reflectors. A few of the boats had clear lamps equipped with clear prismatic, porcelain, or translucent glass reflectors.

Ferry boats seem to contain some of the few older types of lighting installations where the builders have installed ample fixtures. The lower cabins of the boats investigated by the writer were found to be lighted with carbon filament lamps, giving an average of 1.7 watts per square foot, producing an average intensity of 1.8 foot-candles, 3 feet above the floor, over the edge of the seats, which is the height at which the average reader holds a paper.

The upper cabins were lighted in a manner similar to the lower ones, the lamps, however, averaging but 8 feet 5 inches above

the floor. Illumination measurements showed an average intensity, 3 feet above the floor, over the edge of the seats, of 1.6 foot-candles, at an expenditure of 1.6 watts per square foot.

Outside of the upper cabins is a promenade deck running completely around the boat. There is a bench built against the outside wall, extending the entire length, on each side of the boat. Generally there were no lights on these promenades because the Government controls the use of outside lights. However, light was thrown on this promenade from the lamps inside of the cabin. The foot-candle intensity, 3 feet above the floor, over the edge of the bench, was found to average 0.1.

The carrying of trucks constitutes a large part of the ferry business. The average intensity found 3 feet above the floor, in the wagon compartments, was 0.05 foot-candles, obtained with an expenditure of 0.1 watts per square foot. The lamps were located horizontally on the ceiling 14 feet above the floor, and enclosed in weather-proof globes, protected by wire guards.

While the present lighting of ferry boats is fairly satisfactory, observation showed that it could in most cases be improved. Passengers sitting on one side of the cabin in boats not equipped with reflectors, or frosted lamps, directly face a row of bare lamps on the opposite wall. In reading, the eyes are occasionally lifted from the paper. On such occasions the bright glaring lamps cause the iris to contract quickly; hence, when the eyes are again turned on the paper, it is necessary for them to readjust themselves; this causes a tiring strain, which is irritating, and may even become injurious. Obviously, the way to reduce this glare is to use bowl-frosted lamps equipped with the proper reflectors, or raise the lamps out of the line of vision. Probably a combination of these two methods would accomplish the best results.

Boats lighted with clear lamps are open to the criticism of glare. Those using all frosted lamps, without reflectors, obtain their light at a lowered efficiency, slightly due to the loss by frosting, but principally because a large proportion of the light is thrown to the ceiling and walls instead of being delivered on the passengers' papers. Most of the literature read on ferries consists of newspapers, magazines, etc., having relatively fine print.

For such work an intensity of approximately 3 foot-candles should be supplied on the paper. Bowl frosted lamps equipped with intensive type reflectors will solve the problem. Such an equipment would deliver the light where it is most needed, and, at the same time, avoid glare. The comparatively large number of lamps and fixtures at present in use can be largely reduced by using 100 or 150-watt tungsten filament lamps, correctly spaced. Such an equipment would not only reduce the installation cost, but would also lower the renewal cost. It is cheaper to operate a large unit than a small one; for example, the 25-watt bowl-frosted tungsten filament lamp at present lists at 207 per cent. of the list price per candle-power of the 150-watt bowl-frosted tungsten filament lamp.

The following table showing the conditions as found on typical ferry boats operating around New York City is of interest. It should not be taken as a comparison of different systems. The illumination measurements were taken with a Sharp-Millar portable photometer. Five readings were taken at each station and averaged, from 15 to 25 stations being taken to a cabin, depending upon the uniformity of the lighting equipment. The lamps were operated at their rated voltage. The results shown in the table are the average figures obtained from one or more typical boats of each class and represent conditions as found on different boats.

RIVER, LAKE AND COASTWISE STEAMERS.

The lighting of such vessels presents different problems from those of the ferry boats, not only on account of the different arrangement, but also on account of the attitude of the passengers. On the ferry boat, the passenger takes but a short ride which is usually incidental to a longer ride upon a train. Hence, facility of handling passengers, is one of the main requirements. In the case of the river, lake and coastwise steamers, the runs are much longer, so that the passengers have an opportunity to settle down and adjust themselves to their surroundings; pleasure as well as business becomes the motive of the trip. Hence, ornamentation and arrangements for the comfort and pleasure of the passengers are of much greater importance.

The lighting of this class of steamers may be divided into

TABLE A.

	Type of boat	Type of lamp	Type of reflector	Watts per sq. ft.		Effective lumens per watt		Avg. ft.-candles 3 ft. above floor over edge of seats	
				Upper cabin	Lower cabin	Upper cabin	Lower cabin	Upper cabin	Lower cabin
A	Double deck screw	16--c-p., clear, carbon	Clear prismatic glass	2.12	1.87	0.35	0.31	0.8	0.6
B	Double deck screw	16--c-p., clear, carbon	Hexagonal frosted glass	1.43	1.67	1.01	0.92	1.5	1.7
C	Double deck screw	16--c-p., R. B., all frosted, carbon	None	1.73	2.33	0.70	0.43	1.4	1.5
D	Double deck screw	16--c-p., clear, carbon	None	1.27	1.36	0.91	0.88	1.3	1.3
E	Double deck screw	60-watt, clear, carbon	Clear prismatic glass	1.72	2.21	0.75	0.47	1.4	1.1
F	Double deck screw	40-watt, bowl-frosted, tungsten	Clear prismatic glass	—	1.50	—	2.29	—	3.3
G	Double deck screw	40-watt, clear, tantalum	None	1.67	1.62	2.08	2.35	2.2	3.4
H	Double deck screw	40-watt, R. B., all frosted, tantalum	None	1.45	1.37	1.29	1.95	2.3	2.9
I	Single deck side-wheel	50-watt, clear, carbon	White porcelain	—	1.42	—	1.01		1.5
J	Single deck side-wheel	40-watt, clear, tantalum	White porcelain	—	1.13	—	1.30	—	1.7
K	Single deck side-wheel	16--c-p., clear, carbon	Fancy art glass	—	1.76	—	0.44	—	0.9

"E" and "F" are the same boat. the 60-watt, clear, carbon lamps being replaced lamp for lamp by 40-watt, bowl-frosted tungsten lamps.
"I" and "J" are sister boats.
No account is here taken of height, location, age, cleanliness, etc. of lamps.

five parts: (a) social halls; (b) dining-rooms; (c) smoking-rooms; (d) passageways; (e) state-rooms. These various parts of a vessel will be considered in the order mentioned.

Social Halls.—These halls are used by passengers for a general meeting place. Here they sit and chat, read, or listen to the ship's orchestra. Naturally, such compartments are made as comfortable and attractive as possible. Easy chairs and lounges are scattered around; the decks are carpeted; the walls are frequently decorated, and the lamps arranged more with a view of producing an esthetic effect than efficient lighting.

Investigation showed two distinct types of social halls on steamers running into New York City. On steamers making a

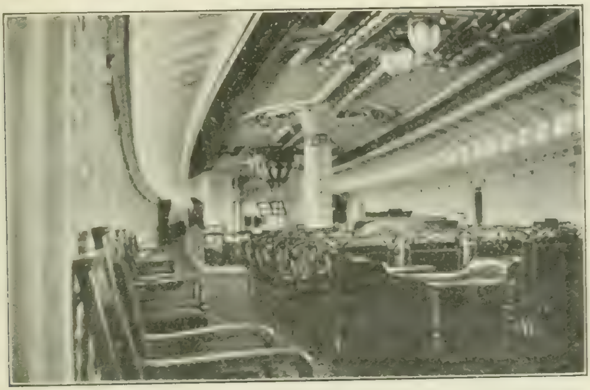


Fig. 2.—Concert hall showing elaborate overhead lighting of a coastwise steamer.

comparatively short run, such as to Fall River, Mass., Albany, N. Y., New Haven, Conn., etc., the social halls were found to have a large well or opening running up one or two decks above the saloon deck. Around these wells were galleries about 5 feet wide, off from which opened the state-rooms. The wells did not extend quite to the stern of the cabin, leaving a floored-over portion on the two upper decks. In addition to the main social hall and well at the stern of the ship there was generally a similar, but much smaller, one at the bow.

The lighting of these halls was found to be usually accomplished mainly from the ceiling of the top deck. The lamps were there arranged on elaborate chandeliers or in artistic designs on

the ceiling. In addition to these lamps, there were a few lamps under the galleries and stern end of each deck below the top one. The lighting of this type of hall was a little more advanced than that which was found in social halls on ships making long trips.

On the latter class ship, the social halls were not quite so elaborate. They were found to be confined to one deck and were lighted with simple, single-lamp fixtures, on both the ceilings and the walls. Reflectors were conspicuous by their absence. In a few instances, however, porcelain reflectors were in use, or the lamps were enclosed in fancy art glass hemispheres. Illumination measurements showed an average intensity, 3 feet above the floor, of 1.1 foot-candles in the social halls of long trip ships and 1.5 foot-candles in the social halls of the short trip class, obtained at an energy consumption of 1.3 and 2.3 watts per square foot respectively.

The lighting of the halls having large wells, *i. e.,* those on the short trip class of ships, could be accomplished more efficiently and without sacrificing the artistic effect by using a smaller number of lamps on the ceiling, substituting for the present numerous 16--c-p. carbon lamps, 100 or 150-watt bowl-frosted tungsten filament lamps, equipped with reflectors giving the intensive type of distribution curve.

In the social halls of long trip ships there is little call for reflectors. The ceilings are low, averaging about 8 feet. Side wall lighting is to be recommended in conjunction with ceiling lamps, thus obtaining a more pleasing facial illumination than where the light comes entirely from overhead. In all cases the ceilings were painted either white or some very light tint, and, in some instances, the walls were similarly finished. Carpets and furniture were invariably either green or red.

Dining-rooms.—The dining-rooms on all the ships were found to be very similar except as to size. The ceilings averaged 9 feet high and were painted white, or some light tint, with walls white, red, or yellow. Round ball enclosing globes were in considerable use with lamps on the ceilings. Such an arrangement gives decorative, though not the most efficient lighting. Here, too, reflectors were conspicuous by their absence. Illumination tests showed an average intensity, 3 feet above the floor, of 1.7 foot-candles

at an average expenditure of 2.0 watts per square foot in carbon filament lamps.

There are two ways in which such dining-rooms may be lighted: one, by general lighting, using lamps correctly spaced on the ceiling, and equipped with the proper reflectors, so as to give an intensity of about 2 foot-candles on the table tops; the other method is by general illumination of rather low intensity, about 1 foot-candle, supplemented by localized or table lighting, with miniature lamps equipped with decorative shades. In this case, round ball enclosing globes can be used to advantage in connection with lamps located on the ceiling. While the former method is more economical, the latter produces by far the more pleasing effects.

Smoking-rooms.—Here again the rooms on the short run ships differed radically from those of the long trip class. In the former

Fig. 3.—Typical entrance lobby and smoking room of a short trip coastwise steamer.

there was generally a large high studded entrance lobby on the main deck, which constituted the smoking-room, while in the latter class the smoking-room was generally on the saloon or an upper deck and had a low ceiling. In all cases, the ceilings were painted a light tint and the walls dark. The furniture was covered with dark leather, and the floors with linoleum. The lighting was produced with all frosted carbon lamps, minus reflectors, located on the ceiling. Illumination tests showed an average intensity, 3 feet above the floor, of 1.3 foot-candles, with an energy expenditure of 2.0 watts per square foot.

In the smoking-rooms the seats were generally arranged around the walls, and the lamps located on the ceiling, several feet out from the walls—a poor arrangement for reading. This could be improved by placing bowl-frosted tungsten filament lamps, equipped with the proper reflectors, on the walls, or ceiling, over the seats.

Passageways.—Extending from bow to stern of the ship were long narrow passageways. These, too, had light walls and ceilings, with green or red carpets, and were lighted by all frosted lamps, minus reflectors, placed on the ceiling in one, two and three-lamp fixtures. Tests showed an average foot-candle intensity, 3 feet above the floor, of 0.8, obtained at an energy expenditure of 1.0 watt per square foot. For such places a rather low intensity illumination of even distribution is desirable. Twenty-five-watt, round bulb, all frosted, tungsten filament lamps placed about 10 feet apart on the ceiling will meet this requirement nicely.

State-rooms.—The state-rooms, invariably, had white walls and ceilings. They were lighted by one all frosted lamp, without a reflector, generally placed in the center of the ceiling. Tests showed an average intensity, 3 feet above the floor, of 0.8 foot-candle, obtained at an energy expenditure of 1.1 watts per square foot.

The lamp located in the center of the ceiling is a poor arrangement. It causes the occupants of the room to continually cast their shadows where they most want to see. The mirror which is located on the wall cannot be used without difficulty. The light could better be located over the center of and one foot out from the mirror. One 40-watt bowl-frosted tungsten filament lamp would give sufficient light for reading and a good general illumination in addition. The following table shows the average conditions found on the type of vessel under consideration. Test arrangements were the same as outlined for ferry boats.

TRANSATLANTIC STEAMERS.

On ocean liners were found, first, second and third-class accommodations. Both the first and second-class quarters were more elegantly decorated and more comfortably fitted than were the best first-class quarters on coastwise ships. The second-class

TABLE B.

Class of ship	Compartment	Type of lamp	Watts per sq. ft.	Avg. ft.-candles 3 ft. above floor	Effective lumens per watt
Short-run	Social hall	16-c-p. all frosted, carbon	2.3	1.7	0.7
Short-run	Dining-room	"	2.9	2.8	0.9
Short-run	Smoking-room	"	2.1	1.5	0.9
Short-run	Passageway	"	1.2	0.8	0.9
Short-run	State-rooms	"	1.0	—	—
Long-run	Social hall	"	1.3	1.3	1.0
Long-run	Dining-room	"	1.6	1.8	1.0
Long-run	Smoking-room	"	1.9	1.9	0.8
Long-run	Passageway	"	1.0	0.9	0.8
Long-run	State-room	"	1.2	1.3	1.0
Short-run	Social hall	25-watt, all frosted, tungsten	0.9	2.4	2.6
Short-run	Dining-room	"	1.0	1.7	1.7
Short-run	Smoking-room	"	1.2	1.6	1.4
Short-run	Passageway	"	0.4	0.9	2.3
Short-run	State-room	"	0.4	0.6	1.0
Long-run	Dining-room	"	0.9	2.7	2.9

rooms were, to a large extent, similar to the first-class ones, but were not furnished quite so elegantly.

Under the first-class quarters come: dining-rooms, drawing-rooms, writing-rooms, smoking-rooms, tea-rooms, children's dining-rooms, ladies' rooms, winter, or palm gardens, gymnasiums, swimming pools, cafes, etc., most of which were duplicated in second-class quarters. In addition to these rooms, there were, of course, state-rooms, passageways, elevators, hospitals, etc.

The lamps in most general use were found to be 16 candle-

Fig. 4.—Dining room of a transatlantic steamer.

power* round bulb, three-quarter frosted, tungsten filament lamps of foreign manufacture. Eight and sixteen candle-power, round bulb, three-quarter frosted, carbon lamps were also in considerable use. In many instances, candle, or miniature flame lamps, were used on the tables and in wall brackets. The fixtures, as a rule, were rather simple, single lamp ones, located on the ceiling. Beaded and cut glass hemispheres were in use on some of the ships.

* Hefnerkerzen or hefner-candles.

The lighting conditions varied so widely (being in each case designed to be in keeping with the particular style of architecture) that little can be said in general about them. It is not the purpose of this paper to go into a long and tedious detailed description. Suffice it to say that the general scheme was overhead lighting, accomplished by single light units, not equipped with shades or reflectors, or else by clusters of lamps enclosed

Fig. 5.—Palm-garden of a transatlantic steamer.

in some sort of dome, supplemented by wall lamps, table lamps, hanging lanterns, etc.

The following table (C) represents the average conditions as found on typical ships of several companies. The watts per square foot are a little higher and the effective lumens per watts are a little lower than is actually used for the general illumination. This is due to the fact that the wattage of a large number of shaded carbon table lamps, candle lamps, etc., producing a relatively small increase in the general lighting, is added to the wattage of the tungsten filament lamps, which produced, by far, the largest percentage of the useful illumination. Test conditions were the same as outlined for the ferry tests.

TABLE C.

Compartments	Type of lamps	Watts per sq. ft.	Average ft.-candles 3 ft. above floor	Effective lumens per watt
Dining-room (1st class)	16--c-p., frosted, carbon	1.08	0.9	0.86
	20-watt, frosted, tungsten and carbon table lamps	1.77	3.4	1.40
Dining-room (2nd class)	16--c-p., frosted, carbon	1.40	1.1	0.75
	20-watt, frosted, tungsten and carbon table lamps	1.11	2.5	2.83
Dining-room (3rd class)	16--c-p., frosted, carbon	0.48	0.6	1.27
Drawing-room (1st class)	16--c-p., frosted, carbon	2.42	1.5	0.62
	20-watt, frosted, tungsten and carbon	0.72	1.5	2.08
Drawing-room (2nd class)	16--c-p., frosted, carbon	1.09	0.8	0.73
	20-watt, frosted, tungsten and carbon	0.75	1.4	1.80
Smoking-room (1st class)	16--c-p., frosted, carbon	1.42	0.7	0.47
	20-watt, frosted, tungsten and carbon	1.60	1.8	1.10
Smoking-room (2nd class)	16--c-p., frosted, carbon	2.80	1.1	0.40
	20-watt, frosted, tungsten	0.74	1.6	2.75
Smoking-room (3rd class)	16--c-p., frosted, carbon	0.56	0.4	0.71
Writing-room (1st class)	16--c-p., frosted, carbon	2.13	0.9	0.42
	20-watt, frosted, tungsten	4.34	4.2	0.99
Gymnasium	20-watt, frosted, tungsten	0.42	1.4	3.48

BATTLESHIPS.

The marked advance in lighting ashore has naturally been noted by the officers of the Navy, and has resulted in a demand for tungsten filament lamps for battleship use. Fighting ships present a little different proposition to the illuminating engineer than do passenger vessels. On warships, not only is the question of efficiency in lighting to be considered, but other conditions, such as, protecting the lamps from accidental breakage, enclosing them against possible powder explosions, providing storage space for extra lamps, general adaptability, interchangeability, etc., must be considered. A battleship, first and foremost, is an engine of destruction. Its ability to fight, fight effectively and hard, is of primary importance. The lighting must be arranged so as to enable the men to use the fighting apparatus to the best advantage. Secondly, a ship is the business office, the factory, the recreation ground, and the home of a thousand men. The happier and more contented these men are, the more efficient will they be. Plenty of light, correctly used, raises the efficiency of the human machine. Realizing these facts, the Government has taken up the lighting of its ships from a scientific standpoint. The lighting of the new ships is being laid out by experts in the Navy Department, who have made a careful study of various illuminants and reflectors. Tungsten filament lamps, equipped with scientifically designed reflectors are being used.

A battleship, as far as the lighting goes, may be divided into four parts: (1) Main and gun decks; (2) passageways; (3) officers' quarters and offices; (4) engine, fire and dynamo rooms.

The main and gun decks consist of compartments in which are located the 3, 5 and 6 inch guns, offices, barber shops, galleys (kitchens), etc. Three times a day they become the crew's mess (dining) room. At night the men sleep there in hammocks strung from the ceiling. These compartments average 7 feet 6 inches from floor to ceiling, and vary from 105 feet long by 22 feet wide to offices but 8 feet square. On dark days, and in stormy weather, when the ports are all closed, artificial lighting must be used. At night there must be sufficient light to allow men to find their way around and yet it must not shine in the eyes of the men sleeping in hammocks strung from the girders

across the ceiling. These conditions present a difficult lighting proposition, complicated by the location of fixtures, pipes, etc., installed after the lighting equipment is in place. On most of the ships these decks have been lighted by scattering 16--c-p. carbon lamps, in clear glass enclosing globes, around the ceiling, for day use, and placing 16--c-p. lamps in clear glass globes on the bulkheads or walls about 4 feet above the floor, for night use. In the new ships the clear glass enclosing globes are being replaced by prismatic glass, so spaced as to get a uniform distribution of light. The bulkhead lamps are being enclosed in frosted globes. The intensity of illumination is being greatly raised by replacing the 16--c-p. carbons with 40-watt tungsten filament lamps.

The passageways in a ship consist of narrow halls about 8 feet high by 6 feet wide, and varying from 50 to 200 feet in length. The principal passages are the berth-deck, wing and center line passages. In the berth-deck passages are hung, three layers deep, the round canvas bags in which the blue jackets keep their clothing. Above these are placed the ditty boxes. During the day these passages are principally alleyways, from one part of the ship to another; at night they become the reading, writing and dressing rooms of the men. The wing and center line passages are vital parts of the ship, especially the latter, which is in the very heart of the ship. Through this passage go many of the lighting, telephone, and other electrical systems, of utmost importance to the control of the ship. The ammunition for the guns is sent up from the magazines to these passages, carried along on endless belts, and hoisted by electric hoists to the guns on the decks above. The passages are lighted entirely by a row of bare incandescent lamps in clear enclosing globes along the wall exactly level with a man's eyes. The effect of glare is exceedingly marked. Due to the large number of conduits on the ceilings of these passages and their proximity to a man's head, it would be impractical to place reflectors on the ceiling. An improvement over the present system could be obtained by placing the lamps at the intersection of the wall and ceiling in 45 degree reflectors, staggering the lamps down the passage.

The officers' quarters consist of living rooms averaging 12 feet long by 8 feet wide by 8 feet high, also the mess, or dining-rooms.

With the exception of the mess rooms, the rooms are not large or regular enough to allow of an even distribution of ceiling fixtures. Desk and portable lamps are used to a large extent. One 60-watt bowl-frosted tungsten filament lamp in an extensive type shade, could be used to advantage on the ceiling of each room, for general illumination, and 25-watt tungsten filament lamps, in desk lamps, equipped with green shades. The mess rooms could be lighted to advantage with 60-watt bowl-frosted tungsten lamps in extensive type shades, on the ceiling. At present they have 16--c-p. carbon, or 25-watt tungsten filament lamps, in frosted enclosing globes, on the ceiling and in 5-lamp chandeliers over the tables.

In the engine, fire and dynamo rooms, the lighting is accomplished by 16--c-p. clear carbon lamps in vapor tight, clear glass globes, protected by wire guards. In ships having large turbine rooms, and a high ceiling for the dynamo room, 400-watt tungsten filament lamps, equipped with steel reflectors and wire guards, have been used to advantage. On ships having their engine rooms filled up with the complicated machinery of powerful reciprocating engines, also the fire rooms, 150-watt tungsten lamps, equipped with steel, enameled reflectors, will make a great improvement.

The introduction of drawn wire filaments has made tungsten lamps practical for the rough use received on a battleship. A large number of these lamps, ranging from 25 to 500 watts, were installed on the U. S. Steamship "Washington" in December, 1910. Since then it has been through battle practise, the tropics, the extreme cold of a Maine winter, storm, full power run, in short, all the various conditions encountered by our ships. Twenty per cent. of the lamps installed were burning on July 1, 1911, at which time the test was ended, the lamps having averaged well above their rated life.

In conclusion, the author desires to thank the following companies who, by their hearty coöperation, enabled him to obtain the data presented in this paper, also the officers of the various ships for their courteous and valuable assistance in making the tests:

Municipal Ferry, New York City; West Shore Ferries of New

York Central Railroad; Delaware, Lackawanna & Western Railroad; Pennsylvania Railroad; Erie Railroad; Central Railroad of New Jersey; Interborough Ferry Company; Long Island Ferry Company; Union Ferry Company of New York and Brooklyn; Hudson River Line; Southern Pacific Company; Clyde Steamship Company; New England Navigation Company; Old Dominion Steamship Company; Hudson River Navigation Company; United Fruit Company; Ocean Steamship Company of Savannah; Cunard Line; Hamburg-American Line; North German Lloyd; United States Government, Navy Department.

THE INFLUENCE OF SPECTRAL CHARACTER OF LIGHT ON THE EFFECTIVENESS OF ILLUMINATION.*

BY M. LUCKIESH.

The velocity of light in the free ether of inter-planetary space is independent of the color or wave-length. However, this is not the case in refracting media for in such media the waves not only travel slower than they do in space, but waves of different length travel at very different velocities. In such media as are commonly used as refracting substances the long waves travel faster than the short ones, and the difference in the velocities of two rays of different wave-length in a certain medium is a measure of the dispersion of that particular medium for those rays. As a result of this difference in velocity the rays become separated and the light is said to be dispersed.

Transparent prisms of glass disperse composite light into its various component colors. A simple lens may be considered

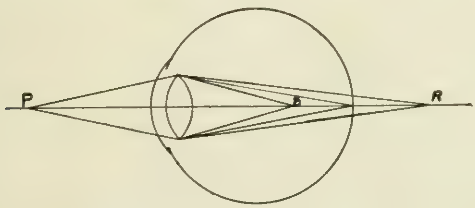


Fig. 1.—Effect of chromatic aberration in the eye.

as having been produced by the revolution of a thin prism (of varying angle) revolved about its shortest edge; hence, an image of the point P, fig. 1, will be formed at B if the point is illuminated by blue light or it will appear at R if illuminated by red light. A lens which does not focus rays of different wave-length at the same point is said to be non-achromatic and this objectionable defect is called chromatic aberration. An optical system free from this defect is said to be achromatic. If the point

* A paper read before the Chicago section of the Illuminating Engineering Society, March 21, 1912.

be illuminated by white light the various rays will come to a focus on the axis from B to R and as a result an indistinct image will be produced. The distinctness of the image in the latter case will depend upon the luminosity of the lights of the various colors composing the white light. The indistinctness will be greatest when the luminosity of the extreme rays—violet and red—are very great in comparison with that of the other rays present. Fortunately our commercial light sources have distributions of energy throughout the spectrum such that a certain middle region is usually much brighter than the extremes of the spectrum. This fact makes it possible to see distinctly with a non-achromatic eye. It is seen if a white screen be placed at R the image will have a blue fringe around it and if the screen is

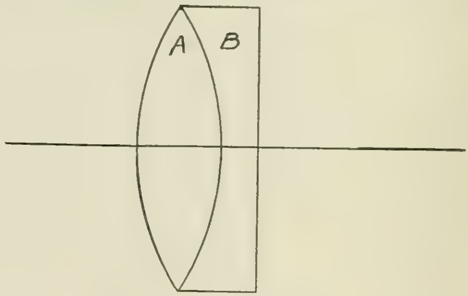


Fig. 2.—An achromatic lens.

placed at B there will be formed a red fringe around the image. This can be verified very readily with any simple lens. The ratio of the velocity of light of a certain wave-length in a refracting medium to the velocity of light in free ether is called the refractive index of the substance. Newton, who discovered that white light was made up of various colors which could be separated by passing the light through a prism, thought that the dispersion was proportional to the refractive index. This caused him to decide that it was impossible to construct an achromatic lens and he therefore bent his efforts toward the construction of reflecting telescopes. Later, believing that the eye was achromatic, Dolland succeeded in making achromatic objectives. The independence of dispersion and refractive index makes it possible to construct lenses which will focus all the visible rays at very nearly the same point. A, in fig. 2, represents a double con-

vex lens of crown glass and B a plane concave lens of flint glass of higher refractive index than the crown glass. This combination will give deviation without dispersion and if carefully calculated will give exactly the same deviation to two colors widely separated in the spectrum, and very nearly the same deviation to the other colors with the result that rays of different refrangibility come together at nearly the same point.

The eye is not achromatic as was for a long time believed, and it is the consideration of the influence of this defect on the effectiveness of illumination which forms the basis of this paper. The fact that the eye is not corrected for chromatic aberration is readily shown. If a luminous point be viewed through a prism a linear spectrum will be seen. The same result can be accomplished by shortening the slit of a spectrograph and focusing a source of light on it. This linear spectrum if focused on a ground glass cannot be distinctly seen at the same time throughout its extent. A normal eye will see the red end in good focus at a great distance while at a very close range only the blue will be in focus. At intermediate distances the yellow will be in focus while the extremities of the spectrum will appear very decidedly out of focus. This experiment is more striking if the spectrum is viewed through a cobalt-blue glass. A proper glass will show two absorption bands leaving red, yellow-green, and blue bands on which the eye can be focused.

In this connection the accommodating power of the eye is of some interest. The eye is focused by changing the shape, and thereby the focal length, of the crystalline lens. When the eye is at its extreme range of accommodation for blue light at near vision it is seen by inspecting fig. 1 that at that range red rays cannot be focused. The reverse is true at the other extreme of accommodation. The writer finds no difference in his ability to focus red or blue light throughout a wide range of distances. At a distance of about six inches the blue end of the spectrum could be focused only with greatest difficulty.

It follows from the foregoing remarks that monochromatic light should produce a better defined image than light of an extended spectral character, when the image is produced by a lens not corrected for chromatic aberration. An increase in visual

acuity should therefore result from the use of monochromatic light. Visual acuity is the ability to distinguish detail and is measured in arbitrary units. Dr. Louis Bell[1] compared the acuity of the eye in tungsten and mercury-vapor tube lights and obtained results which indicated a decided advantage for the mercury arc light. Dr. Bell's experiments were carefully executed and showed without doubt a considerable difference in the amount of the two lights required for equal case in distinguishing detail. The superior defining power of mercury-vapor light was attributed by Dr. Bell to its monochromatic character, about 90 per cent. of the luminosity being due to energy radiated in a narrow region of the spectrum, namely the yellow-green region. A luminous vapor radiates energy in certain localized regions and in general is said to have a line spectrum. The visible spectrum of luminous mercury vapor from the Cooper-Hewitt lamp consists of lines, the principal ones being at $408\mu\mu$, $436\mu\mu$, $546\mu\mu$, $577\mu\mu$ (double), most of the luminosity being due to the two lines, $546\mu\mu$ and $577\mu\mu$.

It occurred to the writer that the question of the superior defining power of monochromatic light could be settled by using purely monochromatic light and avoiding the difficulties involved in the photometry of lights of different color. The green mercury line was isolated by using an absorbing solution of potassium bichromate and neodymium-ammonium-nitrate. This gave at once a purely monochromatic light. This green line was accurately matched in hue by a combination of glasses placed before a tungsten lamp producing a resultant green light of extended spectral character. These two lights could be compared by the ordinary methods without any difficulty because they were of the same hue. Other lights of same hue but differing in spectral character were also used. The photometer shown in fig. 3 was used. At *a, a,* was placed a two column page of printed matter which was viewed from *c*. *b, b,* were mirrors which reflected light from the sources L_1 L_2. At *d, d,* were placed the absorbing solutions. *c* was a thin black partition. All readings were taken at 1 meter distance. The results obtained by the writer with an illumination of 2 foot-candles indicated that for the same acuity

[1] *Elec. World*, May 11, 1911, p. 1163.

about 1.75 times more light of extended spectral character was necessary than light of purely monochromatic character. These results agree very well with those obtained by Dr. Bell[2]. Other experiments also indicated a superior defining power for monochromatic light. The criterion in the above work was that of distinctness of the type and as uncertain as such measurements

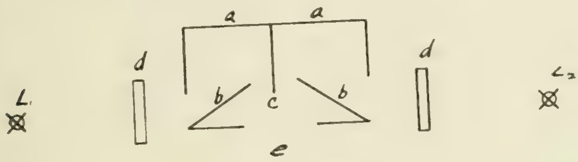


Fig. 3.—Diagram of acuity photometer.

must be, surprisingly consistent results were obtained. By viewing both sides of the photometer simultaneously movements of the pupil were eliminated. It was found on investigation that the pupil did not change in size under the influence of either light. It was necessary to eliminate pupillary movements in these experiments because visual acuity and chromatic aberration depends upon the size of the pupil. With the addition of two other observers the experiment was repeated with the Ives[3] acuity object which lent itself very satisfactorily to the work although the resulting illumination in this case was only 0.6 foot-candles. The acuity object which was placed at *e*, fig. 3, consists of two black line gratings etched on glass and by rotating them with respect to each other about an axis perpendicular to their plane faces lines of any desired width are obtained. The characteristic of the acuity object is that it has a constant transmission coefficient regardless of the width of the lines. A plain white paper was placed at *a*, *a*, and with the drum of the acuity object turned so that the lines were invisible settings for equal brightness could be made. These values obtained by the three observers agreed very closely and they were further checked with a flicker photometer. With the background illuminated by the monochromatic light an observer made ten settings for visual acuity. The acuity object was then set at the mean of these values and with the

2 Loc. cit.

3 *Elec. World*, April 14, 1910.

background illuminated by the light of extended spectral character ten settings were made by varying the illumination until the lines could just be distinguished. The results obtained by the three observers indicated an advantage in defining power for the monochromatic light. The amounts of light of extended spectral character required for the three observers were respectively 4.9, 5.1 and 1.33 times the amount of monochromatic light required for equal acuity. The spectra of the lights used in the work are shown in fig. 4 while the results obtained are shown in table I. Cases I, II, and III show the results of the writer

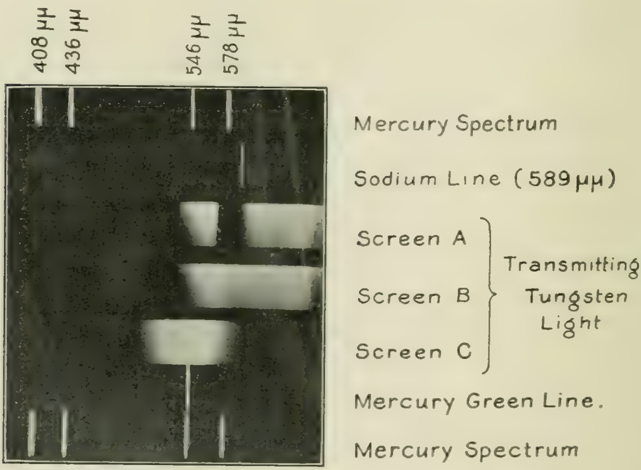


Fig. 4.—Spectral character of lights used.

obtained by use of printed type and the apparatus shown in fig. 3 and lights of spectral character shown in fig. 4. Case IV shows the results of the three observers using the Ives acuity object.

The superior defining power of monochromatic light having been quite conclusively established, it of course became of interest to know in just what monochromatic light visual acuity is greatest. Considerable work had been done on the subject but no investigator had used purely monochromatic light of equal brightness throughout the spectrum. Mr. J. S. Dow[4] measured the acuity in lights of different colors obtained by means of incandescent electric lamps screened with gelatines and solutions of

[4] *London Ill. Eng.*, Vol. 2, p. 233.

various colors and arrived at the conclusion that the blue-green end of the spectrum is somewhat more advantageous for close work but not so good as red light for the illumination of objects or patterns to be distinguished at a distance. Mr. S. W. Ashe[5] used red, green, blue and clear glasses with an incandescent lamp as a source. He found acuity less for the red and increasing in the order green, blue and clear glass for the same illumination. The spectrum through clear glass extends presumably over a

TABLE I.

TABLE SHOWING RATIO OF ILLUMINATION.

Case	Screen	Source	Color of transmitted light	Approximate illumination (ft.-candles)	Advantage of more nearly monochromatic illumination in distinguishing detail
I	A C	Mercury tube Tungsten lamp	Green mercury line Green	2.0	1.75
II	A B	Tungsten lamp Tungsten lamp	Yellow Yellow	4.0	1.33
III	None A	Sodium line Tungsten lamp	Yellow Yellow	0.5	1.66
IV	A C	Mercury tube Tungsten lamp	Green mercury line Green	0.6	(P.W.C.) 4.90 (M.L) 5.10 (H.E.I) 1.33

greater range than the colored lights; therefore, according to Dr. Bell's work and that of the writer the acuity should be less if there were no other factors which largely influence the defining power of the light. According to Macé de Lepinay the more refrangible portion of the spectrum is less defining than the red region. L. Loeser[6] used red, green and white papers on which black characters were printed. The papers were brought to equal brightness and acuity was determined by noting the greatest distance at which the observer could distinguish the details on the paper. By this method he obtained results which indicated a greater acuity for green light than for red light. The characters on the white card could be distinguished at nearly as great a dis-

[5] *Elec. World*, Feb. 25, 1909.

[6] Graefe Archiv. f. Oph. 69, p. 479.

tance as those on the green card. A serious defect in his measurements is the fact that the distances not being constant the accommodating power of the eye complicates the results. The light from the colored papers of course was not monochromatic.

W. Uhthoff[7] has measured acuity in monochromatic spectral light of various wave-lengths. The curves in fig. 5 which are

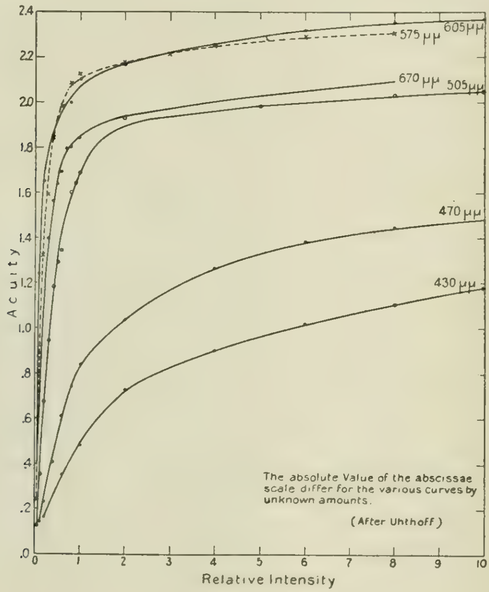


Fig. 5.—Relation of acuity and intensity for light of various wave lengths.

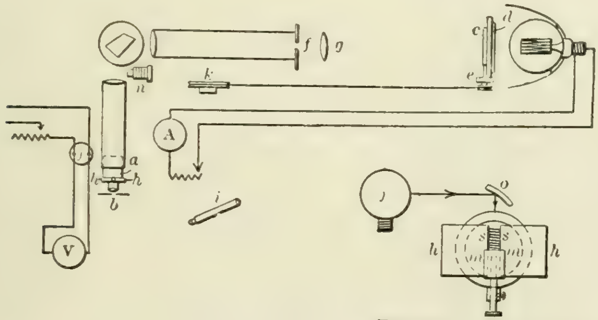
plotted from his data show the variation of acuity with intensity. Unfortunately the abscissae of the various curves bear no known relation to each other so that no conclusion can be drawn as to the variation of acuity in lights of equal brightness but of different colors. The curves, however, show that as for white light, acuity in monochromatic spectral light changes less and less rapidly as equal brightness units are added. It must be remembered that in order to vary acuity in arithmetical ratio the illumination must be varied in geometrical ratio. This is a point too often neglected in considering the acuity method of photometry. Others have also investigated the question but to the writer's

[7] Graefe Archiv. f. Oph. 36, p. 40.

knowledge none has used monochromatic light of equal intensity throughout the spectrum.

Owing to the conflicting results and the fact that in most of the previous work the spectral character of the lights used is not stated, it seemed of interest to determine the defining power of light from various regions of the spectrum. In order to eliminate as far as possible the effect of the chromatic aberration of the eye a narrow portion of the spectrum was used, the light which entered the eye being therefore practically monochromatic. With the proper arrangement a very intense spectrum can be obtained by the use of a prism and on account of the low luminosity values of the extremes of the spectrum it is necessary to start with the highest possible brightness.

The apparatus used by the author is shown diagrammatically



Eye piece converted into an equality of brightness photometer.

Fig. 6.—Diagram of apparatus.

in fig. 6. A Hilger constant-deviation spectroscope was used and the various parts of the spectrum were viewed consecutively through the eye-piece *a*. The width of the eye-piece slit could be varied by means of the slides *h, h*, and a very narrow portion of the spectrum could be viewed. The Ives acuity object *c* was illuminated by a 500-watt tungsten lamp in a parabolic reflector. From this an illumination of 1700 foot-candles was obtained at 1 foot from the tip of the lamp. The light was directed on a ground glass *d* in front of the acuity test-object. By revolving the drum *e* the width of the lines can be decreased until they become too small to be distinguished, the transmission of the

test-object remaining constant. These lines were focused on the collimator slit *f* by the lens *g*. The drum was actually turned by means of a pulley and belt *k*. The position of the drum was read by means of the telescope *i*. These conveniences were added in order to eliminate the distraction arising from undue shifting of the head or body in making observations. The drum readings are very nearly proportional to acuity. In the eye-piece there is a pointer normally used as an index when the spectroscope is used for determining wave-lengths. On this pointer was cemented a small piece of magnesia-coated cardboard which was illuminated by the light from the lamp *j* reflected from the small mirror *o*. This cardboard formed one-half of the field of an equality-of-brightness photometer. The shape of the field is shown in enlarged detail in the lower right hand corner of fig. 6. *ss* represents the portion of the spectrum being viewed. Across this are seen the lines of the test-object when the drum *e* is in such a position that the lines are coarse enough to be visible. *mm* shows the magnesia surface, whose top edge is inclined away from the observer enabling it to receive light from the mirror *o*. The lamp *j* was all-frosted, producing a uniform illumination on *mm*. The normal focussing distance for the writer's eye is about 14 inches and all observations were made at this normal reading distance.

The procedure was as follows: The voltage of lamp *j* was set at a value which gave the desired illumination on the magnesia surface *mm*. The voltage was kept constant. The illumination on the test-object was varied by varying the current through the 500-watt lamp. With the wave-length drum set as far as practicable toward the extreme short-wave end of the spectrum and with a constant voltage on the comparison lamp several settings were made for equal brightness by varying the current through the 500-watt lamp. The mean value of the current readings was used while acuity readings were being obtained. During the settings for equal brightness the drum *e* was set so that the lines were invisible. The lamp *j* was extinguished while ten acuity readings were made by revolving the drum *e* until the lines just disappeared. Fatigue was eliminated as far as possible by resting the eye for some time after taking

a number of observations at each wave-length and by starting at different points of the spectrum. A 2.5 mm. artificial pupil was used. The illumination on the magnesia surface was 4.2 foot-candles. The resultant brightness was somewhat lower than that due to an illumination of 4.2 foot-candles on a white surface owing to the absorption of the eye-piece lenses and the 2.5 mm. pupillary aperture.

The data found in this manner are shown in fig. 7 by the curves which extend from 500$\mu\mu$ to 660$\mu\mu$. The writer obtained many curves of the same general character as I and II indicating that

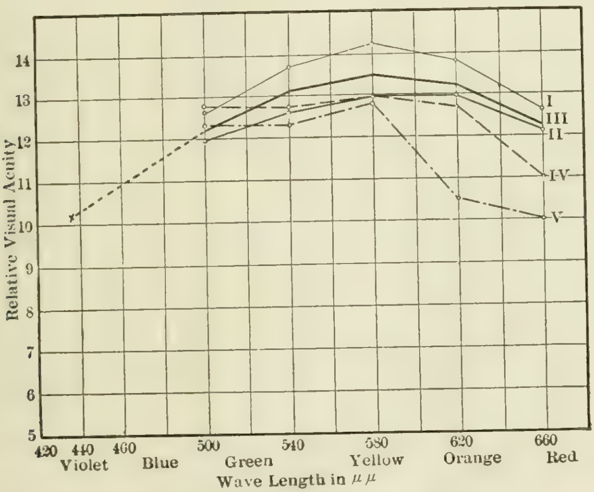


Fig. 7.—Variation of acuity with wave-length of light.

for his eye at least there was a considerable variation in acuity throughout an equal-brightness spectrum. Curves I and II were obtained on the morning and afternoon of the same day illustrating the fact that visual acuity is quite a variable function. Curve III is a mean curve for the writer's eye and was obtained by averaging about fifty observations obtained under identical conditions at each point in the spectrum. These observations extended throughout a period of two weeks. Curves IV and V were obtained by other observers and represent a mean of only ten observations at each point. For extending the investigation into the blue and violet region of the spectrum the best source

available is the mercury vapor lamp. A number of acuity readings were taken for the three bright lines, 436$\mu\mu$, 546$\mu\mu$ and 578$\mu\mu$ (double). These results are shown in fig. 8. Curve VI was obtained by the writer and Curve VII by the observer who had obtained Curve V. If Curve VI is reduced to fit Curve III it extends the writer's mean curve as shown in fig. 7.

It was at first thought that the difference in focus for red and blue rays would cause appreciable differences in the acuity settings if the lines were not focused at each point in the spectrum. This

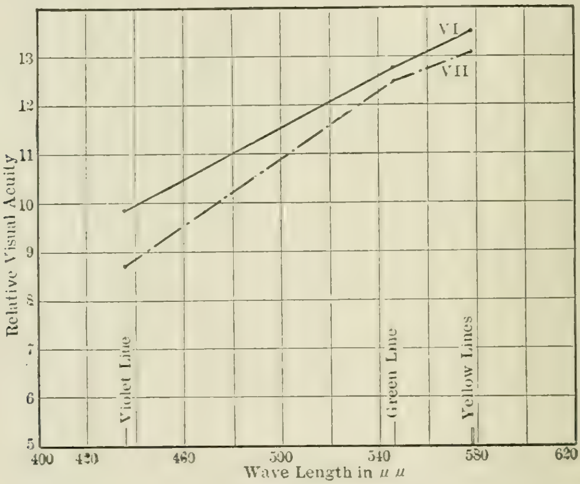


Fig. 8.—Acuity in mercury spectrum.

was thoroughly tested out in the first part of the work by focusing the lines for red rays and taking acuity readings throughout the spectrum without refocusing. Next the lines were focused for blue-green rays (500$\mu\mu$) and acuity readings again taken at all points without readjusting the eye-piece. Finally, the eye-piece was adjusted at each station and acuity readings were taken. In the three cases the same general result was obtained as far as could be determined. Of course the natural fluctuations of the acuity function are so large that the possible effects due to difference in focus might have been masked. Further experiments also showed that the writer could focus his eye with equal ease in any region of the spectrum at the normal reading distance

used which was about 14 inches. Throughout the work, however, care was taken to focus at each station except in the series just described.

Justification for using the equality-of-brightness photometer is found in the fact that throughout a wide range of illumination visual acuity varies much more slowly than brightness. A large error in brightness settings would therefore be necessary to introduce appreciable change in the visual acuity measurements. The relative changes of acuity and brightness as determined are shown in table II. The unit of relative brightness is the illumination used in the preceding work. It appears from the data in the table that for equal variations in brightness visual acuity varies more rapidly at the extremes of the spectrum than it does in the middle region. At $580\mu\mu$ a decrease in visual acuity of only 5 per cent. is obtained when the brightness is decreased 75 per cent. In curve VII the brightness at $436\mu\mu$ must be increased several hundred per cent. in order to obtain the same acuity as at $580\mu\mu$. The data presented in table II are subject to the limitations necessarily imposed by the fact that each value of relative acuity was obtained from a mean of only ten readings by one observer. However, the data are sufficiently reliable to show that variations in acuity throughout the spectrum cannot be considered due to errors in brightness measurements. Aside from the above argument it should be stated that the writer obtains at ordinary illumination practically the same results by the flicker and equality-of-brightness methods, and settings made with the latter method are quite consistent.

In drawing conclusions from the data shown graphically in figs. 7 and 8 more weight is given to curve III which is a mean curve of several taken under identical conditions so far as they were under the control of the observer. The curves obtained by the two other observers, while irregular owing to the fewer observations, show the same characteristics as shown in curve III. It is quite evident that visual acuity depends not only on the spectral character of the light but also on the wave-length. The extremes of the visible spectrum show less defining power than the middle region, the maximum acuity appearing to be in the yellow region. The writer realizes that the above data are incom-

TABLE II.

Wave-length	Relative brightness	Relative acuity[1]
660μμ	1.00	1.00
	.25	.85
620μμ	4.00	1.05
	1.00	1.00
	.25	.93
580μμ	4.00	1.05
	1.00	1.00
	.25	.95
540μμ	4.00	1.08
	1.00	1.00
	.25	.88
500μμ	4.00	1.08
	1.00	1.00
	.25	.82
436μμ	1.00	1.00
	.25	.83

[1] The values of relative acuity in the last column are only comparable with those in the same group. Groups cannot be compared with each other.

plete; however, there can be little doubt that acuity is greatest in the middle region which indicates that the eye does not follow Lord Rayleigh's theorem which calls for a greater resolving power in the blue region. This law which he deduced and verified for ideal physical conditions states that for constant aperture the resolving power of a lens is inversely proportional to the wave-length of light used. The eye, being such a defective optical instrument and involving in its operation many physiological and psychological factors, can hardly be expected to follow the purely physical laws of optical instruments.

While Uhthoff's[8] work was not done with monochromatic lights of equal brightness throughout the spectrum interesting conclusions can be drawn from it with the assistance of the writer's data. Uhthoff measured acuity in various regions of the spectrum of the light from a gas flame. Obviously the greatest luminosity being in the yellow region acuity would be expected to be greatest at that wave-length. As the luminosity decreases toward the extremes of the spectrum, finally reaching zero value at the limits, acuity diminishes rapidly. Unfortunately the luminosity curve of the gas flame is not given, thus limiting the usefulness in his investigations. He obtained acuity curves for four

[8] Loc. cit.

intensities. These are shown in fig. 9. It will be noted that the maximum of the acuity shifts slightly toward the red end of the spectrum as the intensity decreases. This is sort of a reversed Purkinje shift. From these data it will be seen as shown in table II that acuity changes more rapidly with intensity in light from the extremes of the spectrum than it does in light from the middle region. While Uhthoff's work indicates a slight reversed Purkinje effect his results are not conclusive because the work of Koenig and also that of Macé de Lepinay and Nicati indicate a regular Purkinje shift for the blue end of the spectrum while the red and yellow regions undergo no shift at all.

The dotted line in fig. 9 shows the acuity curve obtained by a

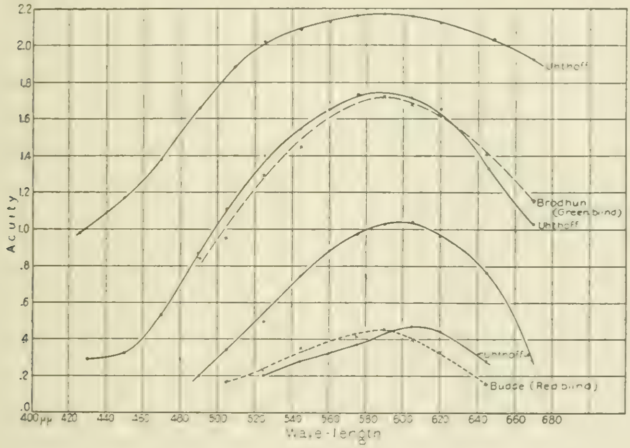


Fig. 9.—Acuity in the spectrum of a gas flame at various intensities.

red-blind observer at the same intensity as Uhthoff's lowest curve. The dashed line is the acuity curve for a green-blind observer at the same intensity as the adjacent full-line curve. The maxima of the acuity curves of the color blind observers do not occur at the same wave-length as the maxima of their respective luminosity curves. The latter are not reproduced here.

On account of the fact that the ability to distinguish detail depends on the spectral character and wave-length of light it is evident that equal values of illumination derived from different light sources should vary in their effectiveness. A practical diffi-

culty in the use of monochromatic light which will give maximum acuity is the distortion of color values and the most practical solution is to use a sufficient amount of light of such character that will give proper color values and cause no difficulty in seeing. In cases where the surroundings are free from color and the work is of a character which demands high detail-revealing power it should be of considerable advantage to use that light which has the greatest defining power. Where such work is being done the illumination should preferably be measured by the acuity method because aside from the spectral character of the light, the distribution and diffusion of the light affects acuity. One practical difficulty in the use of an acuity photometer is its extreme insensibility and another is that the measurements vary much more with various observers than measurements by other methods. In fact it seems that very little could be accomplished in this manner. Another method would be to measure such illuminations with an ordinary photometer assigning acuity constants which would depend on the illuminant, its surroundings, its position relative to the work, and the distribution and diffusion of the light. These constants must be obtained by long research and thorough investigation of all the factors on which acuity depends. Either method involves so many difficulties that there is little encouragement at the present time to alter the established methods of measuring illumination; however, the second method seems more desirable than the first. It must be remembered that in the case of general illumination the eye is very often only concerned with the vision of comparatively large surfaces which present a low degree of brightness difference between one another and not with fine detail presenting the highest contrast such as reading print. The acuity method in such a case would be unjust.

An experiment was carried out which illustrates the injustice of acuity measurements where the object of the illumination is not the revelation of fine detail. The acuity object used in the previous work was illuminated from the rear side by tungsten light through an opal glass. The lines were viewed through a purple glass, diminishing the brightness very considerably yet increasing acuity. This amounts to stating that in some cases a

red light added to a blue light will give less acuity than either source alone. This shows that brightness values obtained by the acuity method cannot be added. This fact is an obvious one yet it shows that for many purposes for which light is used the acuity method would give misleading results and would offer an unfair comparison. Upon inquiring among several men who are devoting their time to the problems bearing on scientific illumination it was found that the concensus of opinion was that only a small part of our "seeing" is done by observation of fine detail and much by observation of differences of light, shade and color, except in very special cases.

CONCLUSIONS.

In so far as the effectiveness of illumination is influenced by the detail-revealing power of light the following conclusions are drawn:

The chromatic aberration of the normal eye is approximately two diopters. Monochromatic light produces a more well-defined image on the retina than light of extended spectral character. Consequently illuminants emitting most of their light in a certain narrow region of the spectrum are superior for use in distinguishing fine detail.

For a constant-brightness spectrum of a brightness corresponding to a practical illumination (about 3 or 4 foot-candles) visual acuity is greatest in the yellow region ($580\mu\mu$). Unfortunately the light which has the greatest defining power would badly distort color values so that its practical use is limited.

Visual acuity varies much more slowly than brightness, varying in arithmetical ratio when brightness is varied in geometrical ratio. For equal brightness variations acuity changes more in light from the extremes of the spectrum than it does in light from the middle region.

The accommodating power of the eye is of importance in determining visual acuity in lights of different colors. For near vision blue light is more readily focused while for distant vision the eye focuses red light with greatest ease. However, for normal reading distances there seems to be, for the writer's eye at least, no discernible difference in the ability to focus lights of different colors.

It would be desirable in certain cases to use the acuity method in determining the effectiveness of an illumination, but its extreme insensibility and the variation in the readings of different observers are against its use for practical purposes. In these cases the most practical method will be found in the use of an ordinary brightness photometer for measuring illumination and assigning a constant which depends on the illuminant, its position, surroundings, etc. Of course these constants must be determined through investigation. In many cases, however, the usual photometric methods are more just than the acuity method.

At the same illumination it is probable that the revealing power of most artificial illuminants of extended spectral character will not differ by a measurable amount.

DISCUSSION.

Mr. T. H. Aldrich: I should like to ask Mr. Luckiesh whether any tests have been made as regards changing the color value of any illuminant, such as the tungsten lamp, after its light has been reflected by either an opal prismatic or an opaque reflector against any colored ceiling or wall, to determine whether the color value of the light is changed materially? Have any tests been made with monochromatic light, such as the mercury-vapor light, whereby orange or red rays have been introduced by the use of the tungsten lamp, to thus make the spectrum of the mercury-vapor light more comparable with the spectrum of daylight?

Mr. J. R. Cravath: When investigating visual acquity it is quite possible, as Mr. Luckiesh intimates, to get up artificial laboratory conditions, which do not take into account large factors of influence occurring in actual daily use of light. For example, in the work[1] that I did last summer in attempting to determine the effect of surroundings on the amount of light different individuals thought they wanted with which to read. I didn't find out very much about the effect of the surroundings on the eye.

[1] J. R. Cravath, "The Effectiveness of Light as Influenced by Systems and Surroundings," Trans. I. E. S., vol. vi, p. 782.

but I did find it made a great deal of difference from how many directions the light happened to be falling on the paper.

As Mr. Luckiesh has said, about the only place where this question of color of light comes up in commercial practise is in the application of the mercury-vapor lamp in comparison with others, and these results doubtless explain some of the popularity of the mercury-vapor lamp for industrial purposes, where apparently the intensity of the illumination is not very high. It has been claimed for a number of years that this light has qualities which make it especially suitable for seeing details. It is only recently that scientific investigation has confirmed those claims.

I should like to direct attention to one other point in practical illumination right here to-night. I think most of us (I know I have) have been sitting through this talk with a surprisingly small amount of eyestrain or discomfort. Some of us have been meeting here in Chicago frequently in a room where there is a large white screen which we have to face all the time, and that screen was very highly illuminated. Some of us also go occasionally to the orchestra hall, where it used to be the custom to turn out all lights except those lighting the sound shell, and we would sit during the evening looking at that very light-colored sound shell, and the result in most cases was not agreeable. Here in this room we have a fairly dark background only moderately illuminated. It seems to me we have a practical point right here, that we want to look after in general surroundings of audience rooms.

Mr. George C. Keech: I should like to ask Mr. Luckiesh if any of the observers in these experiments of his wore eye-glasses. I would also like to ask at what intensity does acuity begin to vary as the logarithm of the intensity. Also, have any experiments been made to determine whether the light of greatest acuity value cause the least eye fatigue, that is, is there less fatigue under greater acuity conditions?

Mr. M. Luckiesh (In reply): In answer to the question raised by Mr. Keech, I will say that all the observers, from whom data were given, wore glasses. I have expressions from a number

of casual observers whom I could not press into service, but from whom I got expressions of opinion, and there was no question in anybody's mind that the printed matter illuminated by monochromatic light was far more distinct. The fact is the type seemed to stick right out as though embossed on the paper. That was very evident throughout all our work.

In regard to the intensity at which the acuity curve turns here, I am quite positive it is about one-tenth of a foot candle. It is at a low illumination so that all these arguments hold throughout the range of practical illumination.

In regard to the relation between acuity and the logarithm of illumination there are two straight lines of different slope which merge into each other at about one meter candle.

Regarding the experiments of acuity and monochromatic light and the fatigue factor, there has not been much done besides one piece of work[2] by Dr. Williams, in collaboration with Dr. Bell, and that hardly had the element of fatigue in it. That is, they examined a number of persons who had worked a long time in mercury-vapor light, such as battery charging men and others who were working under mercury-vapor light entirely, and found that there were no ill effects. Immediately upon coming out from under the influence of that light, they showed a blindness to certain colors, but it was merely temporarily, and the monochromatic light did not seem to show any permanent effects. Some of them had worked under mercury-vapor light as long as six months.

Now a number of us have made the statement at different times that the fact that all the elements of the eye are not exercised when we use such a light source as mercury-vapor light, which radiates light only in a few wave lengths, may lead to permanent injury or permanent effects. Of course that is merely argument. Those tests seemed to indicate that there were no permanent effects. There are a great many problems to be solved along that line, which involve a matter of time and a great many subjects.

[2] *Electrical World*, vol. 57, p. 1163.

In regard to the matter of different kinds of reflectors changing the color of the light,—of course some of them do and some of them don't. It is a very easy matter to see if they do. I am not well enough acquainted with the different kinds of commercial glassware to give any ideas regarding the color change; but the effect would be negligible. Of course, it is an easy matter to change the quality of light by using any kind of colored glass.

In regard to the change in color value by reflection from walls, of course it does change considerably. Take a room with green walls, and we would notice quite a greenish tinge in the photometer field under proper conditions. As a matter of fact, color is only relative, and we do not ordinarily see those color changes in the photometer, just as after night a tungsten light looks white enough to us; whereas in the middle of the day it looks quite yellow. But of course reflection from walls does change the color of the light on the test plane and every colored object in the room assists somewhat in changing the color of the original light.

Mr. Aldrich has also asked a question pertaining to experiments of adding red light to merury-vapor light to approach nearer daylight. I know of some experiments that have just been made on that problem. Dr. Cooper Hewitt has just added a fluorescent reflector to his mercury vapor lamp. Now of course we all know the unpleasant effects of mercury-vapor light on colors and it is due to the fact that all the colors are not present. In order to see any color as it would appear in daylight one must have the same distribution of energy throughout the spectrum as in daylight. Now the fluorescent reflector of the mercury-vapor lamp simply adds some red. It is quite effective in eliminating some of the displeasing color distortions; however, it is not much nearer to daylight; it simply adds some red that was not there. What it needs is a green band also, then the color of the integral light would be fairly good. As it was before, the mercury-vapor lamp was a bluish green, now it is a bluish red or a pink, and it is not much nearer daylight in integral value than it was before.

Mr. T. H. Aldrich: Carrying out your argument, I would

like to ask regarding changing the color value of light by reflecting it against colored walls and ceilings, that is, if the light from the tungsten lamp when directed against a ceiling having a light blue tint (of course I realize there would be a considerable loss in absorption) would not the resultant light on the plane of usage be nearer to the color value of daylight than it was before? Would the change in color be perceptible to the eye? Would it be noticeable in the spectroscope or colorimeter?

Mr. M. Luckiesh: One could notice it, but it would be an infinitesimally small increment toward daylight. There is no way to obtain proper color value by selective reflection without reducing the efficiency very much.

Mr. T. H. Aldrich: That is, reflecting it through different colored glass screens in order to get the daylight spectrum? In making the tests for visual acuity with the mercury-vapor lamp, how large an area was used in getting that color into your focus? How many square inches of the surface of the mercury-vapor lamp were used? Was the whole lamp used, the regular long tube, about four feet long?

Mr. M. Luckiesh: The light was passed through the prism of the spectroscope and a small rectangular field was seen. The lamp was not seen at all.

Mr. T. H. Aldrich: In making a just comparison between the visual acuity of the mercury-vapor lamp and the tungsten lamp, was much stress laid upon the fact of the comparative great difference in intrinsic brilliancies, of both units and the color of light? The tungsten lamp filament has approximately an intrinsic brilliancy of 1,000 candle-power per square inch, and the mercury-vapor lamp has approximately 15 candle-power per square inch. Where one type of light is compared with another, I believe that in judging the inherent color value of one light against the other, from a visual acuity standpoint, that considerable stress should be laid upon the intrinsic brilliancies of both units in question. I know of one installation that I came in contact with recently, where mercury-vapor lamps were in use in a draughting room for some time; the wattage consumed was approximately 2,322 watts as compared with a tungsten installation wattage of 3,000, after the change was made. I had no flicker photometer for meas-

uring the foot candles by the mercury vapor light. With the tungsten light some 6 foot-candles were measured. The wattage with the tungsten lamps was 2.25 watts per square foot, as against 1.7 per square foot with the mercury-vapor previously. Some twenty draughtsmen are working under this new installation of indirect lighting, and with success. I may possibly be wrong in my deductions, but from practical observations I believe the question of intrinsic brilliancy and color values is worthy of careful consideration.

MR. M. LUCKIESH: Whether intrinsic brilliancy plays much part, is an unsettled question. As a matter of fact I think that we are coming to the opinion that intrinsic brilliancy plays a less important part than we heretofore considered. However, I have taken pains here to say that in these cases the most practicable method will be found in the use of the ordinary brightness of the photometer for measuring illumination and assigning a constant which depends on the illuminant, its possible surroundings, etc. I had in mind that very thing, the character of light, intrinsic brilliancy, and all things that are directly concerned with the illuminant, and without question these measurements should be made in practise. That is where they are used, and that is where they should be compared.

MR. T. H. ALDRICH: One thing I notice in practise which I think is one of the strong points of the mercury-vapor lamp, is the large square inch area that is used in this unit; it also has a very low intrinsic brilliancy, with very small square inch surface. I think this is quite noticeable to the layman in the factories where it is installed.

MR. M. LUCKIESH: In regard to the layman, I don't have much confidence in him as an investigator. I think he is the last fellow one ought to go to for final opinions. If you want to put a safety device over some gear to avoid the possibility of getting his arm in there, he will object to it because it is a departure from what he is used to. While your point is all right in regard to the intrinsic brilliancy, that is in regard to the fact that the intrinsic brilliancy may play some part, (I have no doubt but what it does play some part), I think it is of less importance

than we used to think it was. I think it is largely the amount of light than comes into the eye. Of course we know that it is not well to have a light piercing one's eye, and we know that we are not much troubled with after images from low brilliancy sources. I don't want to be understood as saying that intrinsic brilliancy is of little importance I merely want to say I don't know how important it is.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. MAY, 1912. NO. 5

COUNCIL NOTES.

At the meeting of the council held in the general office, 29 West Thirty-ninth Street, New York, May 10, the committee on financial policy presented a report signed by a minority of the committee recommending a division of the society's membership into three classes. The proposed classifications were discussed at length, but the report was laid on the table for the June meeting when all the members of the council shall have had an opportunity to consider the recommendations.

The chairman of the committee on illumination primer, Mr. L. B. Marks, reported that the primer which had been revised many times was about completed. He added that the final report of the committee might be expected at the June council meeting.

Mr. Norman Macbeth, chairman of the 1912 convention committee, reported that the convention would probably be held during the second week of September, although the dates had not been decided upon definitely. Niagara Falls, Canada, was the place selected at the April council meeting.

A special committee consisting of Messrs. L. B. Marks, Louis Bell and J. R. Cravath, which had been appointed at the April meeting of the council to consider what policy the society should pursue in replying to inquiries pertaining to engineering services, lighting accessories, etc., reported that in replying to such inquiries the society should state that it is not in a position to make any recommendations. The recommendation of the committee was adopted.

Dr. Louis Bell reported orally on a meeting of the committee on hygiene of the eye of the American Medical Association which he had attended. Dr. Bell mentioned that at the latter meeting various suggestions pertaining to research work were put forth tentatively, which if carried out would be of interest to the society.

President Lansingh read an invitation which had been tendered to the society to participate in a congress on hygiene and demography under the auspices of the United States Government in Washington next September. He also read his reply to the invitation in which he stated that the society could not accept the invitation inasmuch as it could not furnish an exhibit, but that the society would, if desired, be glad to arrange for a suitable paper on illumination to be presented at the congress.

Mr. George S. Barrows was appointed chairman of a committee to reconsider a resolution passed by the council in January, 1909, prohibiting the use of trade names in the TRANSACTIONS of the society. Since the adoption of the latter resolution various members of the council have questioned both the advisability and practicability of this policy. It was understood that definite recommendations on the subject would be received shortly from the committee. The other members of the committee are Dr. A. S. McAllister and Mr. Bassett Jones, Jr.

The question of whether the society should publish papers on illuminating engineering, either in toto or in abstract, read before other societies was discussed briefly and later referred to the editing and publication committee. In transmitting this question to the committee for consideration, the council voiced the opinion that it favors the incorporation of matters of importance in the TRANSACTIONS.

A report of progress was received from the committee on nomenclature and standards. A resolution by the committee withdrawing its proposal for an international conference on photometric units pending developments in the Zurich Commission was endorsed.

A monthly report on the current finances and membership of the society was received from the assistant secretary. Payment of April bills amounting to $919.27 was authorized, in accordance with a recommendation of the finance committee.

Progress reports were received from the membership committee, committee on illumination exhibit, committee on reciprocal relations with other societies, committee on nomenclature and standards, advertising committee and the section development committee.

Thirteen applicants were elected to membership.

Those present at the meeting were Messrs. V. R. Lansingh, president; J. T. Maxwell, C. J. Russell, G. S. Barrows, Norman Macbeth, H. E. Ives, A. J. Marshall, L. B. Marks, J. R. Cravath, Louis Bell and P. S. Millar, general secretary.

SECTION NOTES.

CHICAGO SECTION.

"Street Lighting" was the subject of discussion at the meeting of the Chicago section May 23. Numerous interesting written and oral discussions were received from various members of the local and other sections of the society. This meeting concluded the present season of the section.

The following officers were elected for next season: chairman, Prof. Wm. E. Barrows, Armour Institute of Technology, Chicago, Ill.; secretary, Mr. J. B. Jackson, 28 North Market Street, Chicago, Ill.; managers, Messrs. F. A. Vaughn, S. E. Church, J. R. Cravath, Edward Wray, and J. W. Foster.

NEW YORK SECTION.

The New York section held a joint meeting with the New York chapter of the American Institute of Architects in the United Engineering Societies Building, 29 West Thirty-ninth Street, New York, May 2. A paper on "The Relation of Light to Shadow and Color in Design" was presented by Messrs. Bassett Jones, Jr., and Henry Hornbostel. Mr. Jones supplemented the paper with a number of demonstrations showing the influence of the direction of light on a number of ornamental columns and interior designs. The use of color to bring out various details in relief was also illustrated. About two hundred members of the society and the institute were present. Preceding the meeting there was an informal dinner at Keene's Chop House, 70 West Thirty-sixth Street, New York.

The following officers were elected for the ensuing year: chairman, Mr. G. H. Stickney, General Electric Co., Harrison, N. J.; secretary, Mr. Clarence L. Law, 124 West 42nd Street, New York; managers, Messrs. H. Thurston Owens, Albert J. Marshall, Wm. A. D. Evans, Thomas Scofield and W. H. Spencer.

PHILADELPHIA SECTION.

The final meeting of the present season of the Philadelphia section was held May 17 at the Bingham Hotel. Prof. A. J. Rowland presented a paper on the subjects of "Calculation of Illumination" and "Principles of Photometry." Mr. C. O. Bond exhibited various lighting standards which included the pentane lamp, the sperm candle, the Elliott kerosene lamp and others. About 190 members and visitors were in attendance. The usual informal dinner preceded the meeting.

The following officers for the ensuing season were elected: chairman, Prof. A. J. Rowland, Drexel Institute, Philadelphia, Pa.; secretary, Mr. L. B. Eichengreen, 1401 Arch Street, Philadelphia, Pa.; managers, Messrs. J. D. Israel, F. N. Morton, R. F. Pierce, George Hoadley and E. B. Gillender.

PITTSBURG SECTION.

The Pittsburg section held a meeting May 17 in the auditorium of the Western Society of Engineers. A symposium on direct, indirect and semi-indirect lighting in three parts was presented by Mr. Thomas Rolph of the Nelite Works of the General Electric Company, Cleveland, Ohio, Mr. J. G. Henninger of the National Electric Lamp Association, Cleveland, Ohio, and Mr. S. G. Hibben of the Macbeth-Evans Glass Company, Pittsburg, Pa. The paper occasioned considerable interesting discussion. It will appear in the June issue of the TRANSACTIONS.

The following officers for the season 1912-1913 were elected: chairman, Prof. H. S. Hower, Carnegie Technical Schools, Pittsburg, Pa.; secretary, C. J. Mundo, General Electric Co., Oliver Building, Pittsburg, Pa.; managers, Messrs. C. E. Clewell, W. Edgar Reed, E. R. Roberts, W. M. Skiff and S. B. Stewart.

NEW ENGLAND SECTION.

The New England section held a meeting April 29 in the auditorium of the Edison Electric Illuminating Company, Boston. Messrs. Edward Burdett, chief counsel of the Edison Electric Illuminating Company of Boston, Mr. W. W. Freeman of the Edison Electric Illuminating Company of Brooklyn, Mr. W. H. Blood, Prof. H. Kropp and others discussed the subject of "Competition or Monopoly in the Supply of Public Service."

INDIRECT LIGHTING IN AUDITORIUMS.*

BY H. B. WHEELER.

This paper describes briefly the indirect lighting installations in the auditoriums of the Eighth Church of Christ Scientist and the North Chicago Hebrew Congregation, of Chicago, and the Village Auditorium at Glen Ellyn, Ill. It also includes various test data obtained from these installations.

EIGHTH CHURCH OF CHRIST SCIENTIST.

Description of Auditorium.—Fig. 1 shows the interior of the Eighth Church of Christ Scientist. The area under the dome is 60 ft. by 60 ft. with the ceiling 50 ft. high at the center. Each

Fig. 1.—Interior of the Eighth Church Christ Scientist, Chicago, Ill.

side arch is 16 ft. by 60 ft.; the ceiling is 30 ft. high to the center of the arch. Two rear arches, not shown in this picture, are 40 ft. by 60 ft. with ceilings 28 and 24 ft. high.

The decorations throughout the auditorium are light, the ceiling being an ivory white and the walls a cream color. The pews are of dark birch and the furnishings, rugs, etc., are dark green.

* A paper read before a meeting of the Chicago section of the Illuminating Engineering Society, January 18, 1912.

Lighting Fixtures.[1]—The center fixture contains twenty 250-watt tungsten lamps equipped with concentrating reflectors. The tops of the reflectors are 12 ft. from the ceiling. The distance from the ceiling was determined by the distribution curve of the reflector employed in the fixture, which is shown in fig. 2. This fixture is one of the largest indirect units that has

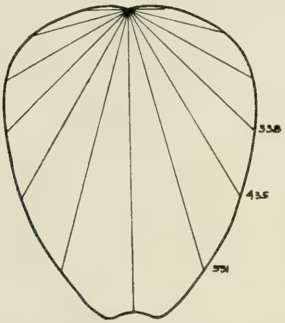


Fig. 2.—Distribution curve of the concentrating reflector (with a 250-watt tungsten lamp) employed in the large indirect lighting fixture.

ever been installed. It measures 7 ft. 6 in. in diameter and 36 in. in depth. It weighs 800 pounds. It is lowered for cleaning by means of a windlass.

Three smaller indirect fixtures hang under each side arch. Each fixture contains five 100-watt tungsten lamps equipped

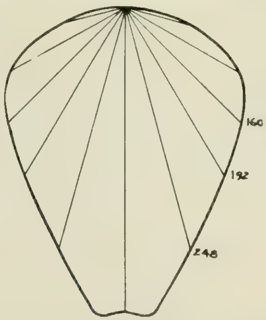


Fig. 3.—Distribution curve of a concentrating reflector (with a 100-watt tungsten lamp) employed in the smaller indirect units.

with concentrating reflectors. The distribution curve of the reflectors employed in these fixtures is shown in fig. 3.

[1] The fixtures, including the reflectors, mentioned in the paper are manufactured by the National X-Ray Reflector Company.

Suspended from each of the two rear arches are three other indirect fixtures. Each of these fixtures is equipped with six 100-watt tungsten lamps fitted with concentrating reflectors like those used in the side units.

The glass blanks of the reflectors are of one piece, plated with pure silver and covered with an elastic enamel to protect the silver from chipping and peeling. The surface of all reflectors is fire-glazed so as to make cleaning easy. The reflectors are corrugated to afford good diffusion.

Fig. 4 shows the equipment of the smaller fixtures. This

Fig. 4.—Interior equipment of the indirect lighting fixture.

equipment consists of a central body to which all the arms fasten. These bodies are arranged so that any number of arms can be used. A socket and shade holder attachment are employed to keep the reflector in a correct position as regards the lamp filaments.

Illumination Data.—Illumination tests were made by the manufacturer of the reflectors between the hours of 6:30 and 9 P. M., January 12, 1912, to determine the average foot-candles of

illumination in the auditorium and to ascertain the efficiency of the entire system with the lamps burning at their rated voltage.

In this particular interior, it was a rather difficult matter to divide the floor area into equal rectangles for stations. Stations that would give a fair average were selected generally in the aisles, although some were taken in the pews.

Fig. 5 shows the floor plan of this auditorium with the numbered test stations. The first test was made with all the lights burning in the main auditorium, in the wings and under the

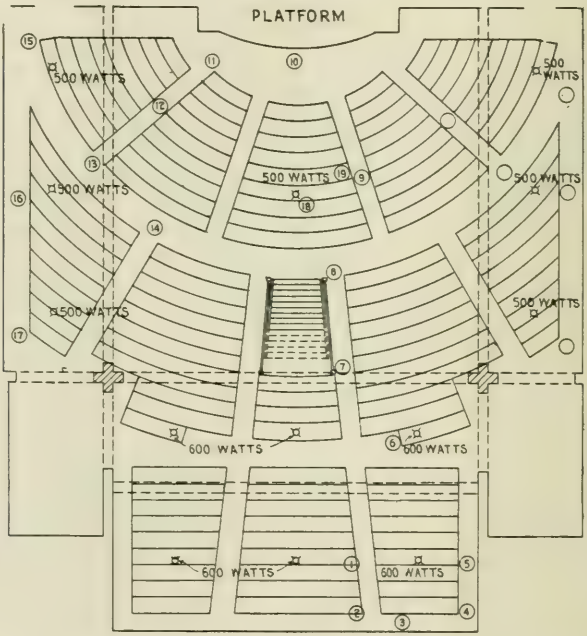


Fig. 5.—The floor diagram of auditorium showing location of test stations.

arches. Readings were taken first at station one and then at the other stations in the order of their numbers. Each station gave a fair average for its particular area. Six illuminometer readings were taken at each station with a Sharp-Millar photometer. Simultaneously voltage readings were taken on the switchboard. The foot-candle readings were averaged at each of the eighteen stations and all reduced to 117 volts; this was the voltage at which the lamps gave their rated wattage, their rating being 113-115 and

117 volts. To determine the socket voltage, the distance from the switchboard to each fixture was scaled from wiring plans; the drop was then approximated and the load at each outlet ascertained. The socket voltage was found to be 101 volts.

Illuminometer readings were next taken with only the large center fixture burning. All illuminometer readings were taken on a horizontal plane 30 inches above the floor.

Fig. 6 illustrates the character of the illumination on a longi-

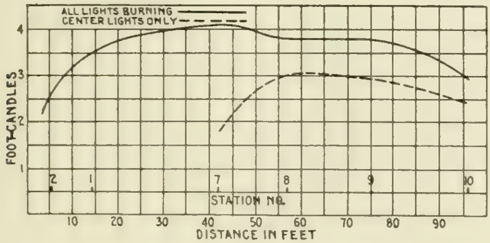


Fig. 6.—Curves showing intensity of illumination over a longitudinal section of the auditorium.

tudinal line through the center of the church. The full line curve represents the results obtained with all units burning; the broken line curve with only the large center unit burning. At the front of the church, inside the rear arches, the illumination dropped off slightly when all lights were burning. With the

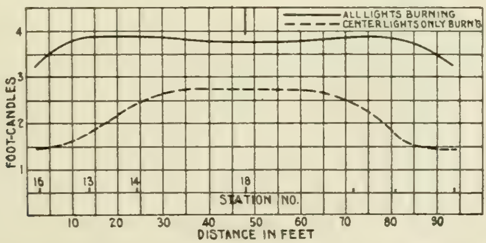


Fig. 7.—Curves showing the illumination over a transverse section of the auditorium.

center fixture alone burning the distribution was, of course, not as uniform, there being a considerable drop at each end of the auditorium. Both curves were plotted from the average of the foot-candle readings at each station reduced to 117 volts.

Fig. 7 shows the illumination results obtained on a line running crosswise through the centre of the church.

The illumination results obtained with all units burning were as follows:

Average foot-candles at 117 volts....................	3.0
Average foot-candles at 101 volts....................	1.76
Per cent. efficiency[2]	26.3

The above-mentioned results represent the average of six illuminometer readings at each station. The wattage was 1.45 per square foot.

TABLE I—ILLUMINOMETER READINGS IN AUDITORIUM OF THE EIGHTH CHURCH OF CHRIST SCIENTIST.

	All lights burning		Centre fixture alone	
Station	Foot-candles 101 volts at socket	Foot-candles at rated volts (117)	Foot-candles 101 volts at socket	Foot-candles at rated volts (117)
1	2.01	3.45		
2	1.36	2.33		
3	1.27	2.17		
4	.74	1.27		
5	1.17	2.01		
6	2.11	3.62		
7	2.37	4.06	1.03	1.77
8	2.18	3.47	1.75	3.00
9	2.18	3.47	1.70	2.91
10	1.72	2.94	1.41	2.42
11	1.68	2.87	1.30	2.22
12	2.02	3.46	1.23	2.11
13	2.26	3.87	1.01	1.73
14	2.25	3.86	1.44	2.47
15	1.46	2.50	.5	.85
16	1.87	3.20	.85	1.46
17	1.27	2.18	.51	.88
18			1.59	2.73
19			1.48	2.54
Average	1.76	3.02	1.21	2.08

With only the center fixtures burning the following results were obtained:

[2] The efficiencies given in this paper were determined from the rated lamp lumens, viz.: 2168 lumens for the 250-watt tungsten lamp and 830 for the 100-watt lamp. A conservative efficiency rating of the reflectors used in the several units is 80%. The reflectors in the small fixture had been cleaned a week previous to the test, while those in the large fixtures were cleaned one month previous to the test. The accumulation of dust on the reflectors during the time prior to the test was slight.

Average foot-candles at 117 volts	2.08
Average foot-candles at 101 volts	1.21
Per cent. efficiency	33.4

The latter result is merely approximate because it was difficult to determine the extent of the area illuminated by the central fixture. It is to be expected, however, that in this case the efficiency would be higher, because the wall loss is less than in the case when all the fixtures were burning.

Table I gives the illumination results obtained at the various stations in the auditorium.

North Chicago Hebrew Church.

Description of Auditorium.—Fig. 8 shows the interior of the North Chicago Hebrew Church. This interior is 70 ft. by 88 ft.;

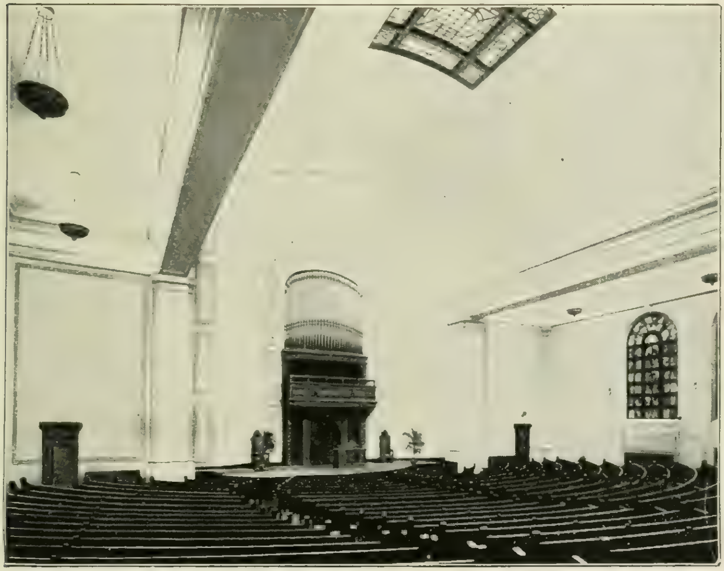


Fig. 8.—Auditorium of the North Chicago Hebrew Congregation.

the ceiling at the center is 52 ft. and under the wings 30 ft.; the walls are light buff and the ceiling is white; the stairs and woodwork are finished in oak. The floor is of cement and the aisles are covered with light rose carpet. In the center of the arched ceiling there is a ground glass skylight 16 ft. by 26 ft.

Lighting Fixtures.—Six indirect fixtures, three on each side of the auditorium, and a battery of 52 helmet-shaped concentrat-

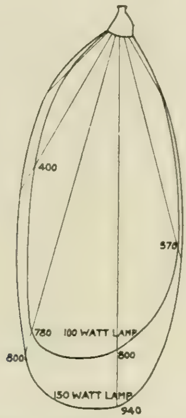


Fig. 9.—Distribution of light about the "helmet" concentrating reflector.

ing reflectors furnish the illumination for this auditorium. Twenty-six of the reflectors are concealed on each side of the arched ceiling on the cornice. The distribution curve of these reflectors is shown in fig. 9. The six fixtures along the sides of the auditorium each contain five 100-watt tungsten lamps with concentrating reflectors having a distribution curve as shown in fig. 3.

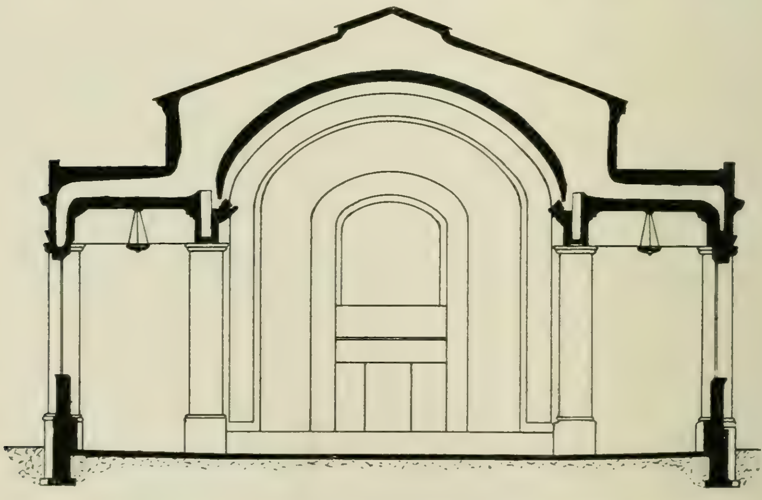


Fig. 10.—Cross-section of the auditorium of the North Chicago Hebrew Congregation.

The tops of the reflectors are 60 inches from the ceiling. Theoretically, this distance is a trifle low inasmuch as there are large wall losses; but in this particular instance the walls being of a light buff and the ceiling of white the decrease in illumination is not very noticeable. The fixtures may be lowered for cleaning.

Fig. 10 shows a cross section of the church. The cove where the battery of reflectors is concealed is shown. The reflectors cannot be seen from practically any part of the church. The reflectors are readily accessible for cleaning.

Illumination Data.—Fig. 11 shows the floor plan of the auditorium with the location of the test stations. The interior, being

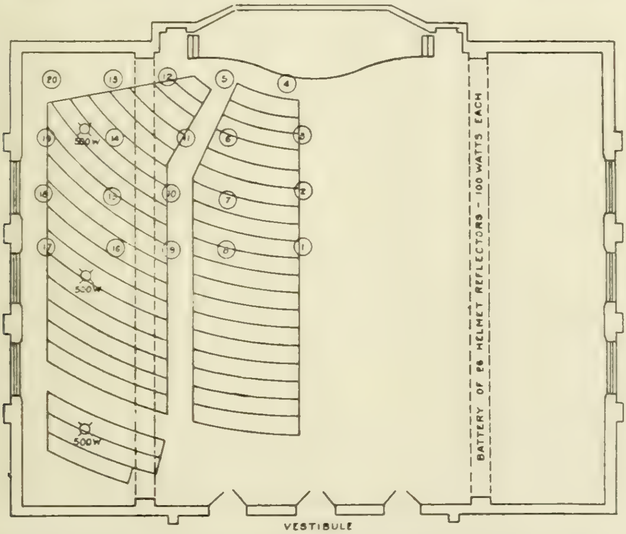


Fig. 11.—Diagram of the auditorium showing the location of test stations.

a symmetrical one, was divided into four equal rectangles. In each rectangle twenty stations were located. Three illuminometer readings were taken as near the center of each rectangle as the pews would permit and the results were reduced to 120 volts. The readings taken at each of the twenty test stations were averaged with the following results:

All Lights Burning.

Average foot-candles at 120 volts....................	2.18
Per cent. efficiency	20.9
Watts per square foot	1.33

The averages of the various readings obtained at the several stations are shown in table II.

TABLE II—ILLUMINOMETER READINGS FROM THE NORTH CHICAGO HEBREW CONGREGATION.

Station No.	All lights burning Average foot-candles at rated volts (120)	Cove lights only burning Average foot-candles at rated volts (120)
1	2.63	2.41
2	2.66	2.34
3	2.65	2.47
4	2.26	1.98
5	2.11	1.65
6	2.38	1.99
7	2.60	1.93
8	2.82	2.11
9	2.43	1.79
10	2.44	1.84
11	2.07	1.29
12	2.13	1.44
13	1.65	1.01
14	1.96	1.05
15	2.02	.99
16	2.12	1.02
17	1.92	.72
18	1.81	.73
19	1.73	.69
20	1.28	.58

The efficiency of the system of lighting in the interior of this church was affected somewhat by the cove construction of the central portion of the ceiling, that is the large skylight, and in that five of the fixtures under the side arches had not been cleaned since the previous November. The batteries of reflectors and one side fixture which were cleaned three weeks prior to the test, were found to be free from dust when examined at the time of test.

From the illuminometer readings obtained at the same stations previously mentioned with only the batteries of concentrating reflectors burning, an average illumination of 1.5 foot-candles was obtained. In calculating this average, readings were taken at the same stations previously mentioned and the results were reduced to 120 volts, the lamps being rated at 116, 118 and 120 volts.

Curves representing the illumination intensity, which were plotted from the illuminometer readings taken at stations 17, 16,

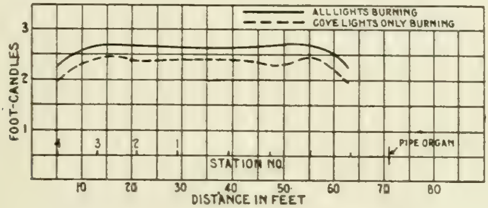


Fig. 12.—Curves showing the intensity of illumination along a central horizontal section of the auditorium.

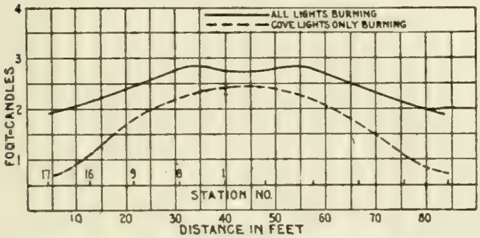


Fig. 13.—Intensity of illumination along section at right angles to a central horizontal line of the auditorium.

9, 8, 1, 2, 3, and 4 with all lights burning and with only the batteries of concentrating reflectors burning, are shown in figs. 12 and 13.

Village Auditorium.

Description of Auditorium.—Fig. 14 shows a cross-section of

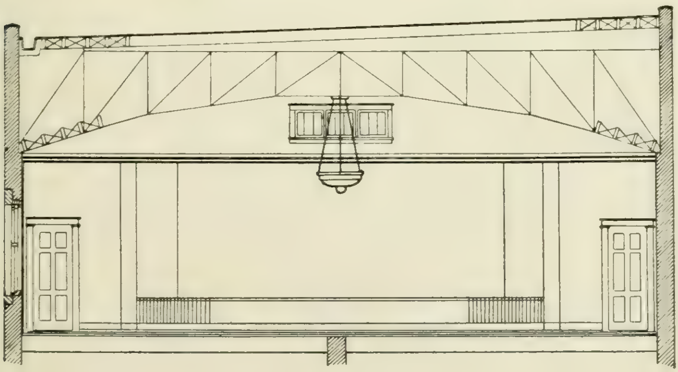


Fig. 14.—Cross-section of the Village Auditorium at Glen Ellyn, Ill.

the village auditorium at Glenn Ellyn, which is 40 by 60 ft. This interior was selected for test in that everything in it was brand new. The ceiling and walls are of a pure white putty coat plaster and the floor is of a very light maple. The ceiling is 15 ft. high in the center of the auditorium; it slopes down to the sides where it is 12 ft high.

Lighting Fixtures.—Three indirect fixtures, each containing seven 100-watt tungsten lamps are suspended 60 inches from the ceiling. This distance was, of course, determined from the

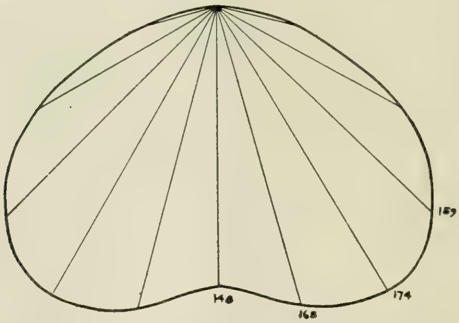


Fig. 15.—Distribution curve of the reflectors used with 100-watt lamp in the lighting units of the Village Auditorium.

distribution curve of the reflectors used in the fixture. Fig. 15 shows this distribution curve.

Fig. 16 shows the floor plan of the auditorium with the location of the test stations.

Illumination Data.—Illuminometer readings were taken at each of the thirty numbered stations and the results calculated as in the two other installations described in this paper. The lamps were rated at 106, 108 and 110 volts; the service voltage averaged 109 volts. The results obtained were as follows:

Average foot-candles at 110 volts	4.20
Per cent. efficiency	0.56
Watts per square foot	0.87

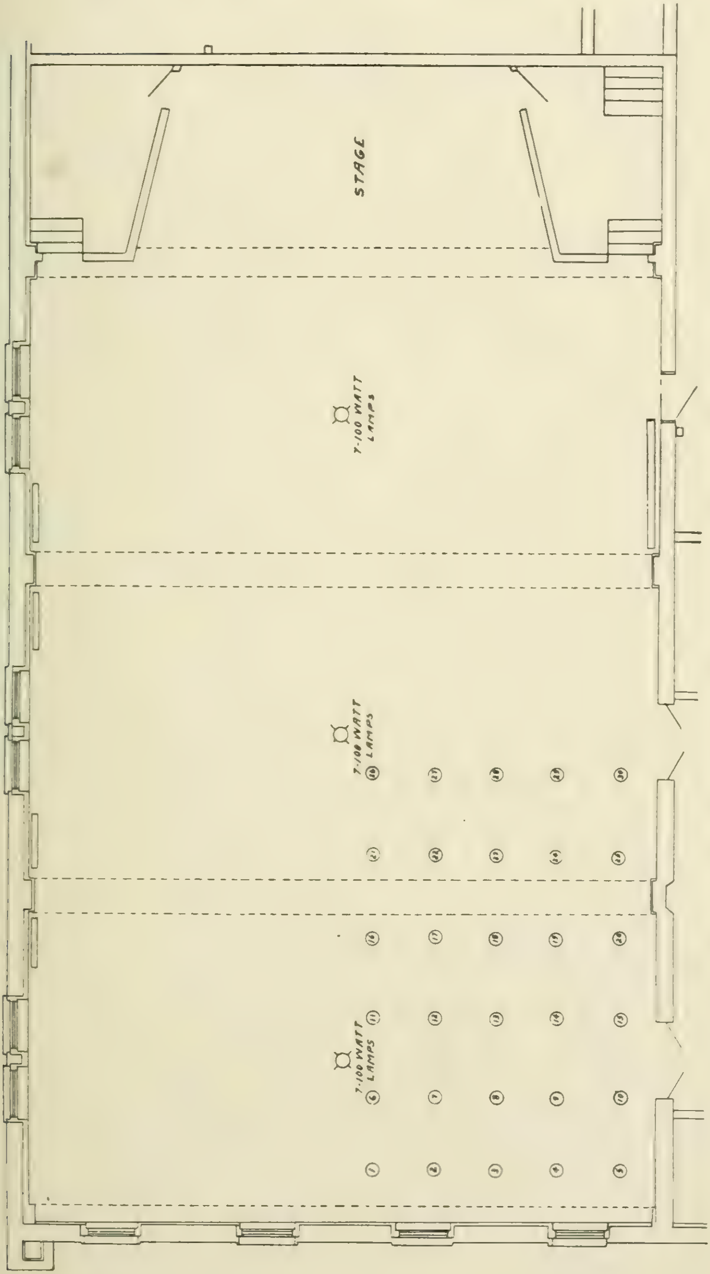


Fig. 16.—Floor plan of the Village Auditorium showing location of test stations.

The latter efficiency figures may seem somewhat high, but when one considers that the decorations are pure white and the floor of white maple and the ceiling has a high reflecting coefficient the correctness of the stated efficiency becomes

TABLE III—ILLUMINOMETER READINGS FROM THE VILLAGE AUDITORIUM, GLEN ELLYN, ILL.

Station	Average foot candles at rated volts 110
1	3.64
2	3.54
3	3.08
4	2.56
5	2.01
6	6.26
7	5.60
8	4.27
9	3.29
10	2.30
11	6.28
12	5.58
13	4.29
14	3.27
15	2.36
16	6.34
17	5.45
18	4.28
19	3.50
20	3.00
21	6.36
22	5.43
23	4.30
24	3.48
25	3.02
26	6.91
27	5.93
28	4.55
29	3.50
30	2.26

apparent. In a paper[3] read by Messrs. Lansingh and Rolph at the Illuminating Engineering Society convention in 1908 an efficiency of 79 per cent. with indirect lighting in a room with pure white ceiling, walls and floor is stated.

[3] TRANS. I. E. S. vol. III, p. 593.

The results of the illumination readings obtained at the various

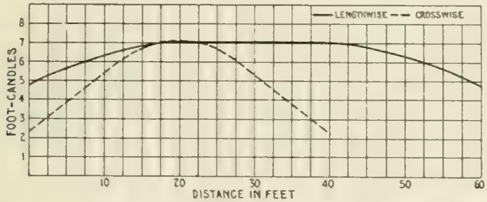


Fig. 17.—Curve showing intensity of illumination in the Village Auditorium.

stations in this auditorium are given in table III. These are shown graphically in fig. 17.

CONCLUSION.

In all the tests discussed in this paper, the same instruments and methods of reducing results were employed. It is hoped that the readings given will be of interest as data obtained from three typical indirect lighting installations of auditoriums under actual service conditions.

SHOW WINDOW LIGHTING.

BY J. G. HENNINGER.

With the inception of the incandescent lamp there opened a hitherto unrealized, perchance unthought of field, both of illumination and of display. Show windows there have been for years, but not in the complete sense that they are known to-day.

One does not have to go far into the pages of history to find records of the store with its big oil lamps, or its myriads of candles. Today actual stores may be found wherein the windows are lighted by means of large oil lamps fitted with big tin shades. The big square paned windows are piled up with merchandise of various sorts, while above all hangs the big old oil lamp.

In the cities gas jets have for a long time furnished all of the illumination to be had for windows. These jets placed along the upper front edge of the window and backed up with bright tin reflectors shed a not unpleasant light over the wares on display.

The carbon incandescent lamp opened a new field. With its introduction, illumination standards were raised and with them the idea as to what constituted a window display.

How these good people did misuse their lamps! They outlined their windows and they outlined this and that, so that with all the good, citizens of the town had rather a difficult task to look past a wall of light to see what was shown in the window. The jump from the oil flame and gas jet to the carbon lamp meant an increase in intrinsic brilliancy from 3 to 8 to about 375 candle-power per square inch.

Science and experience have proven that a brilliancy of 375 candle-power per square inch is far above what can be safely and comfortably stood by the eye; nevertheless, there was quite a period of time during which outline lighting was very popular for show windows.

As I stated once before, window lighting is not new by any means, nor is the show window new, but never before in the history of commerce has the show window occupied the place of prominence that it occupies to-day. What large store is without its window dresser and his equipment? Do not these large con-

cerns spend large sums of money annually on their windows? They obtain the best of plate glass. They put in the handsomest woodwork and fittings. It is their desire to have their windows stand out like an oasis in a desert.

What constitutes good show window illumination? How may one distinguish between a poorly lighted and a well lighted window? "That window is well lighted in which the wares on display are so illuminated as to stand out clearly and distinctly without a thought arising in the observer's mind relative to the manner in which the window lighting is done." I speak with regard to the average individual. It is perfectly obvious that a man interested in window dressing and in illumination in general, will immediately wish to find out all details regarding the construction of the window, the number of lamps used, the size and type of reflector, etc.

A show window may be compared to a stage. Just as the scenic artists strive to produce the most attractive set-ups, so the window dresser strives to produce the most attention-compelling windows of which he is capable.

To sudy show window illumination, the following outline is convenient:

1. Intensity of illumination required in window.
2. Street lighting—Its effect on window illumination.
3. Glare—Exposed lamps.
   Reflection from glass backing.
   Mirrors.
4. Window background—Proper.
   Improper.
5. Reflection from plate glass.
   Reflection of light sources within window.
   Reflection from street lamps.
6. Dress of window, with special reference to the arrangement of wares on display.
7. Light sources, arrangement, reflectors, diffusion, etc.

The intensity of illumination required in any show window will depend upon several things: locality of store, standard of illumination in that locality, and kind of goods displayed.

In a large town, on an important street where signs, neighbor-

ing windows, street lighting, and all are turning the very night into day, the standard of illumination will necessarily be much higher than on a side street or on the outskirts of the town; hence, the merchant must have his windows lighted in keeping with those of his neighbors. It frequently happens in some of our large cities where the standard of illumination on the street is very low that a very moderate intensity of illumination will be quite sufficient. There are a number of small towns where the standard of illumination is considerably higher than it is in towns many times their size. It is partly on account of these facts that engineers, in giving the intensity of illumination required for show windows, say that it may be anywhere from 5 to 25 foot-candles.

Naturally it takes a great deal more light to make a dark colored object stand out distinctly than it does a light colored object. Of course, there are exceptions to this rule. A dark object seen against a light background would obviously stand out much more clearly than an object of the same color as its back-ground; but, stating the average case, much more light is required by a window of dark tone than by one in which the color tone is light; hence, a merchant displaying light goods, need not illuminate his windows to the intensity required by the same window when it is filled with dark goods.

During the past two years while a crusade for great "White Ways" has been pushed so vigorously in many cities, there has been a great deal of discussion as to whether or not the increased intensity of street lighting spoiled the effect of electric signs and windows. There is no doubt that in a number of instances the effect of window lighting has been spoiled by an over generous supply of street lighting. Many merchants have found that they had to double and some times treble the amount of light used in their windows. In some few cases the window lighting has been omitted altogether, the merchant depending upon street lighting to illuminate his wares.

Viewing a window illuminated from the outside is just about the same as viewing a body in a morgue. A window lighted externally can be nothing more or less than "dead" in appearance. As some of the poets have said it is "the light from within"

which is indicative of life. A person viewing a window lighted only by street lamps alone must immediately come to the conclusion that the merchant is either not wide enough awake to energetically get after new business or doesn't care for it.

Street illumination of high intensity cannot but have its effect on window illumination. However, in the average large city, the intensity of window illumination is so high, anywhere from 15 to 25 foot-candles, that the street illumination would have to have an excessive intensity in order that there be no contrast between the two. In my opinion the glare from high candle-

Fig. 1.—A splendid example of glare in window lighting.

power units is the feature of street lighting which is objectionable. A street properly equipped with ornamental standards should in no wise detract from the effect of the show windows. If the intensity of the show windows is so low that the ordinary ornamental standard installation puts them at a disadvantage, it is about time that the merchants were startled out of slumber and persuaded to light their windows.

It hasn't been many years since it was the fashion to illuminate show windows by means of an outline of lamps. Indeed, there are a great many installations today which still glare at the

passer-by. There are some kinds of stores and some localities were outline lighting is a good thing, but these may be classed under the head of "commercial enterprises which wish to attract attention to the institution as a whole" rather than to an individual piece of merchandise which may catch the attention of a possible customer. Outline lighting was never intended to illuminate wares in such a fashion that a person could see them well. It should be classed as display lighting and not as window illumination.

Another form of illumination which is just as objectionable

Fig. 2.—An expensively built window, and nicely dressed, spoiled by glaring light units in the plane of sight.

is the use of high candle-power units in front of a window. It may be a good business getter on the part of the power company or gas company, but it is very poor engineering; to my mind it seems that business obtained upon a more sound and sane foundation would be much more acceptable. Of course, there are exceptions to this criticism. There are a number of small dealers who never would be interested in anything that was not cheap and it is these people who can be cared for very nicely by means of such window illumination. It is scarcely worth while for anybody to bother in particular over such an installation.

The concensus of opinion to-day, I am sure, is in favor of

having the light sources in a window completely screened from view. If the lamps are not properly equipped with reflectors, the reflection from the glass window backing is apt to prove objectionable to persons viewing the window. The eye involuntarily follows the light and anyone who takes time to observe people looking into a show window where the reflection from window backing is bad will notice these people glance up to see where the light is coming from.

The choice of background for a window is a very important proceeding and one which should be made with a great deal of

Fig. 3.—A good window except for the reflection from the window backing.

care. It is impossible to get a background which will show up well with all wares which are apt to be displayed in the windows of the average mercantile establishment. Clear glass in most cases is objectionable, not only due to reflection, but due to the fact that it gives the window no solidity. Ripple glass or various forms of art glass can be successfully used in the rear of a window for the reason that there is practically no surface reflection and its range of color is such that a glass can be chosen suitable for practically any finish of window.

Mirrors may have the effect of giving depth to a window, but unless very carefully used, they are apt to be a great detriment. Reflection of windows across the street certainly de-

tracts from the effect of display. Every passing automobile or street car is pictured in the mirror and the prospective customer will look up in spite of himself. Fig. 5 shows a high, narrow, window fitted with a mirror background which was a much better advertisement for the man across the street than it was for the merchant himself. In my opinion, the thing to do is to put up a neat, substantial appearing window and then arrange to change the background to suit the wares displayed. I have carefully watched the windows of a large store in Cleveland and have noted the fact that the window dresser very carefully observes this principle. The windows, themselves, are finished in mahogany and the hardwood floor, for the greater part of the time,

Fig. 4.—A nicely built window. The background is of a neutral tone. The diffusion is not quite good enough, although the shadows in the window are not objectionable.

is covered with dark green cloth. This combination is excellent for displaying light or neutral colored goods. When the display is changed to dark goods, the background is immediately changed to a light or neutral color; in other words, this window dresser plays contrast between goods on display and background very strongly. If his scheme of display calls for several different colors in goods, he is careful to choose a background which will give him the highest average contrast It is not to be taken from this that sharp contrasts are always desirable. Contrasts of low order are very frequently required to give a window its proper effect. Where individual pieces of merchandise are displayed contrast plays an important part. White draperies, laces, etc.,

are often displayed to best advantage when harmoniously arranged with other wares. Contrast is important, but it must be used with good taste and judgment.

There was at one time a great deal of discussion as to the effect of reflection from plate glass on the illumination in a window. I have come to the conclusion that on the average this effect does not amount to much. In a small window where the light sources are arranged along the upper front edge giving the angle of incidence a high value, a great deal of the light is

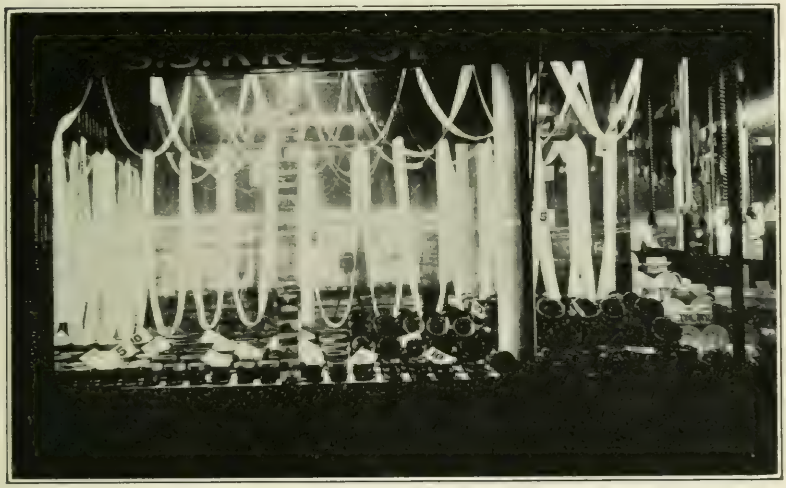


Fig. 5.—A good advertisement for the merchant across the street. The mirrors in the back of the window reflect the image of the store window on the opposite side of the street.

undoubtedly returned to the window. The effect of this, however, is not marked more than a few inches away from the plate glass.

In a window of the same size where the light sources are centrally located the plate glass has considerably less effect. In most of the large stores the lamps in the show windows are almost always placed at the upper front edge of the show window. In most of these windows, it is customary to use curtains of some kind so that the windows may be closed to public view when being dressed. Often these curtains are of plain linen material, while in other cases, they are more ornate, such as

the French type of curtains. Again the windows are sometimes topped off with grill work, or other ornamentation. Where curtains or grill work are used, the light rays from the lamps overhead are, for the most part, cut off from the glass. Those that do reach the glass do so at a very oblique angle, so that they are, for the most part, returned to the window itself. On the whole, however, I think it is safe to say that reflection from the

Fig. 6.—An excellent window. The illumination is of sufficient intensity. The diffusion is good. The background of this window is always carefully selected. The lights shown are the images of lights across the street which are reflected by plate glass of this window.

plate glass of the window plays a very small part indeed in the illumination of that window.

It is obvious that the success of a window does not depend altogether upon the illumination thereof. It is easily possible to have a well lighted window which is a poor advertisement; likewise, it is easily possible to have a window which would be a splendid advertisement if it could be seen. The point to be made in this connection is that the arrangement of display, together with choice of background, is quite as essential as a good system of illumination. I have had occasion to make a careful study of jewelers' windows and have been very strongly im-

pressed with the necessity for careful choice of display. One merchant will dress his window very carefully using the best of material for his backing. In a tasteful manner he will arrange a few of the wares which he wishes to bring especially before the public. If the wares are priced, the tags are put on in a very neat, clean-cut, way. It takes but a glance at a window of this kind to decide that the merchant is conducting a store of quality. On the other hand, when one often sees a store window in which the wares have been piled closely together, the aim being to get the greatest amount of merchandise possible into the space available, he concludes at once that this store cannot very well be

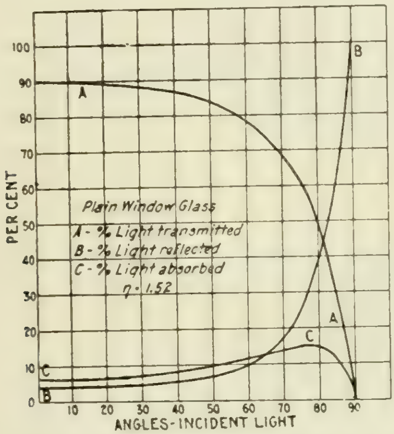


Fig. 7.—Graphic illustration of the effect of ordinary plate glass on light rays incident at various angles.

considered first class; he is more inclined to look for cheap jewelry.

In considering this matter it must of course be conceded that both types of stores have their place; and both types of windows must be lighted to bring out the best that is in them. In the first mentioned window, the general effect is to be that of "quality". In the second case, it is always desirable—at least it seems so—to have the windows a blaze of light. The desire is to impress upon the public that the store is open for business with big value for little money". Often in windows of this latter type, the ceilings, as well as the back and sides, are com-

Fig. 8.—A window of quality and neat display; it is not overcrowded.

Fig. 9.—A bewildering maze watches, hat-pins, bracelets, lamps, clocks, etc.

pletely covered with mirrors so that one looks into an endless maze of lamps, clocks, watches, bracelets, hat pins, etc.

So far a good many of the variables which enter into the illumination of a show window have been considered. A consideration of the arrangement of lamps and reflectors may be interesting. There are two important items which must be kept in mind in designing the illumination of any show window: first, the intensity of illumination must be sufficiently high: second, the diffusion of light must be good. In general, it may be said that light which comes from above and in front of the wares

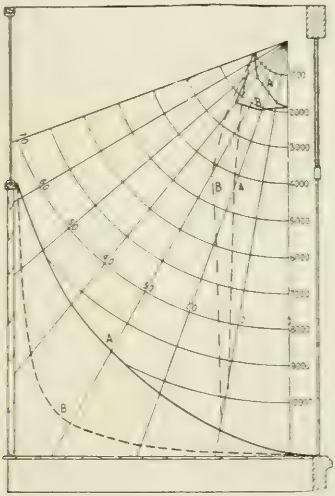
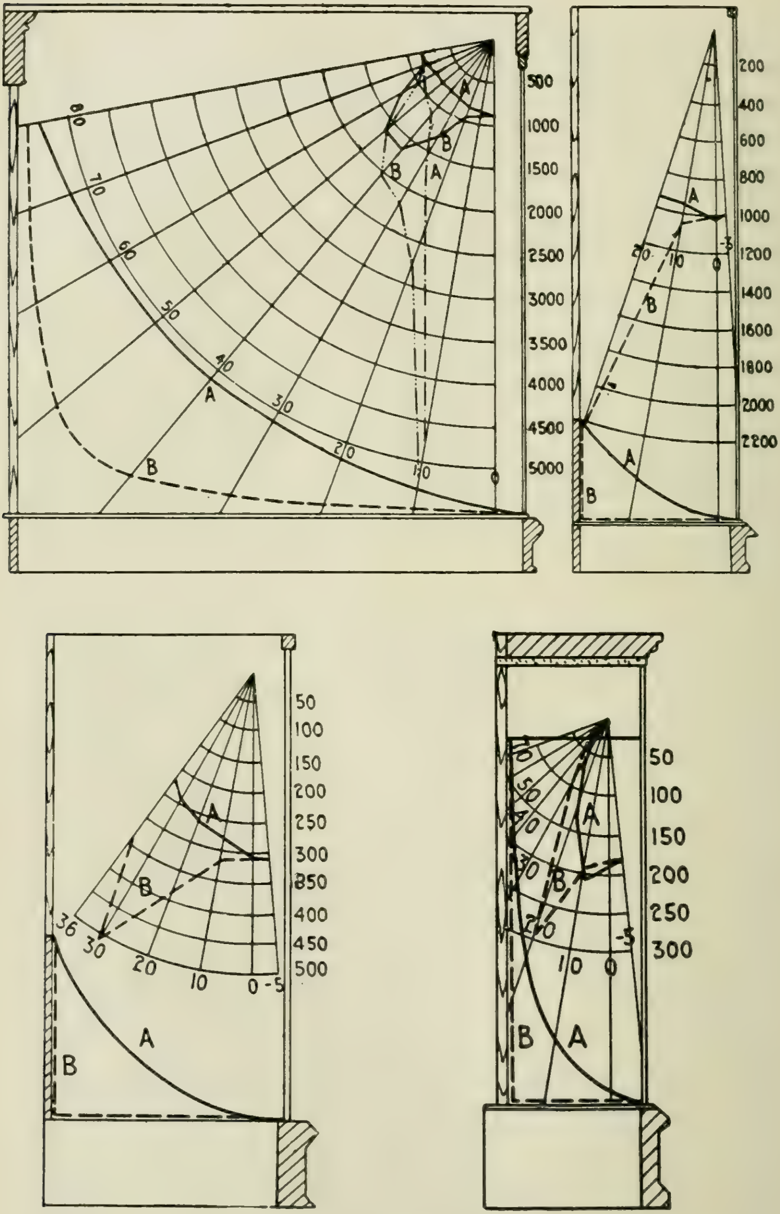


Fig. 10 —Planes of illumination in a very large window.

on display produces the most satisfactory results. In some of the smaller show windows, where the wares are displayed in almost a horizontal plane, the directional value of the light may be almost vertical, while in other cases, where the windows are fairly large and dressed high, the angle of "light throw" will cover quite a range. Rarely, if ever, does the angle of "light throw" need to cover an angle of more than 90 degrees measured in a plane perpendicular to the plate glass of the window and perpendicular to the floor of the same. It is desirable to have a broad throw of light lengthwise of the window because this tends to produce good diffusion. Of course in a small



Figs. 11, 12, 13, and 14.—Planes of illumination in four windows of different sizes and styles.

window where but one or two light sources are used, the angle of "light throw" will necessarily be determined in all directions by the extent of the window.

In looking over the large number of reflectors which are on the market today, one finds that quite a number of the manufacturers have not realized the necessity of, or else have not been able, keeping the majority of the light within 90 degrees in the vertical plane perpendicular to the window. A great number of the reflectors which do keep the light within the 90 degree angle have it poorly distributed. The most of them project too much

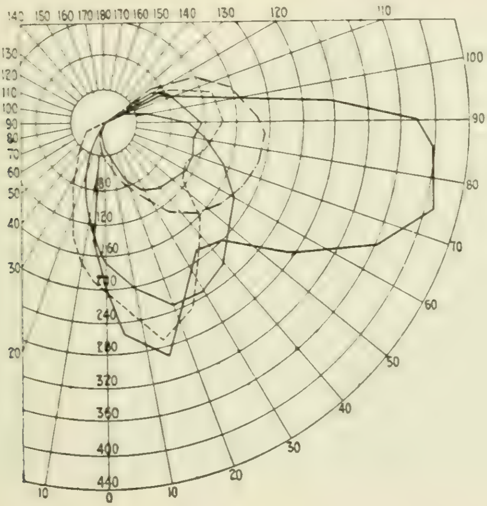


Fig. 15.—Light distribution curves of a 100-watt tungsten lamp equipped with five different styles of window lighting reflectors.

light toward the top of the window. A large number of reflectors which have some good qualities to recommend them have rather weird curves. Many people have been inclined to think that concentrating units placed in a vertical position, at the upper front edge of the show window, are rather poor pieces of equipment. The fact is, that for a great many windows, this is an ideal arrangement.

It is a difficult matter to formulate any set of rules covering window illumination. In order to get the best results each window should be considered individually and that equipment

planned which will give the best results. Cost must necessarily enter in. Where a small number of large units are used, of course, the installation cost is, comparatively speaking, low; while on the other hand, if a large number of small units are used, the installation cost is high. In the first case, the shadows are apt to be sharp and well defined, while in the second case, the shadows are more soft in nature, due to the fact that the light is better diffused.

The use to which a window is to be put should naturally play a most important part in the choice of lighting units. If the dress is inclined to be flat, that is, made up of objects which are prac-

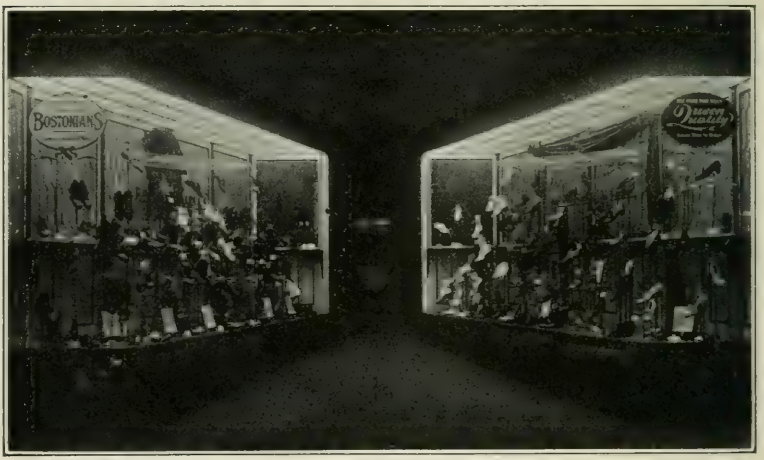


Fig. 16.—A wall-built window with good diffusion and pleasing dress.

tically all in one plane, large units can be sucessfully used. If, on the other hand, all manner and size of objects are to be displayed in all manner of relative positions, then the greater the diffusion, the better. Furthermore, incandescent lamps will burn out, and, where a window is lighted by a small number of large units, the loss of one unit will diminish the illumination considerably; whereas if there is a large number of small units, one or two outages will probably never be noticed.

There is some question as to what should be considered the plane of illumination in a show window. Planes "A" and "B" in figs. 10 to 14 inclusive represent two possible extremes. Large

objects such as dress forms may be set up vertically in a window, but in general the plane of dress will be somewhere between the planes indicated. Fig. 10 represents a very large show window with a high ceiling; fig. 11, a large show window with a low ceiling; fig. 12, a narrow show window with a high ceiling; fig. 13, a narrow show window with a low ceiling; and fig. 14, a narrow show window with a wall case.

In order to show the influence of the plane of dress on the general shape of the distribution curve of a window lighting system, I have assumed a uniform intensity of illumination of 10 foot-candles in planes "A" and "B" and have calculated the candle-power necessary to produce it. The full line curves (figs. 10 and 11) and both curves of figs. 12, 13, 14, show how the effective distribution curve must change to produce the assumed results. It will be noted how curve "A" in each case corresponds in general to the shape of the plane of dress. The question came up

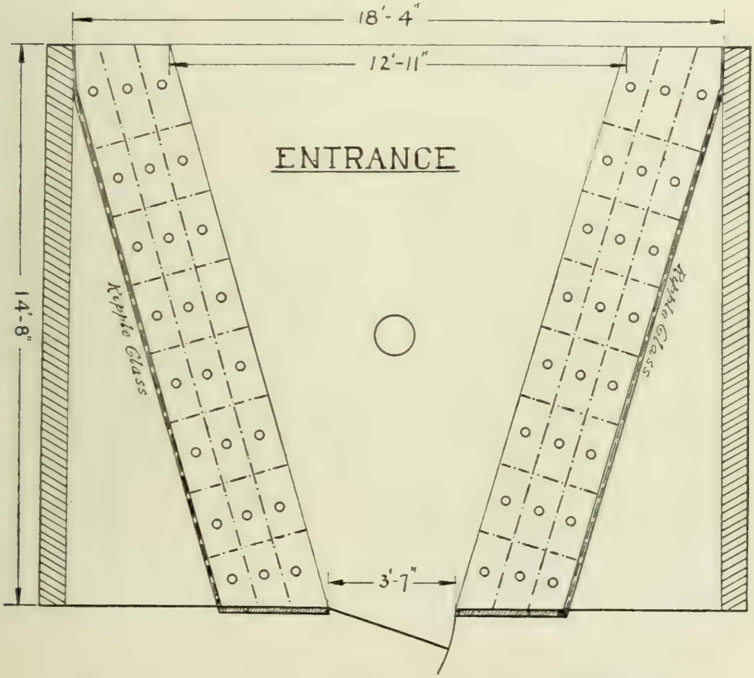


Fig. 17.—Plan of converging windows showing location of lighting units.

as to what light distribution would be necessary if uniform illumination in a vertical plane were considered. The dotted curves in figs. 10 and 11 show the result. It is perfectly obvious from these sketches, which cover the general extremes in show window construction, that the distribution of light necessary is well within a quadrant and any light sent outside of this quadrant is a dead loss. For some windows it is apparent that the light distribution to be most efficient should be within 60 degrees and sometimes

Fig. 18.—A well lighted window. The detail is splendid.

less. An inspection of the entire available supply of window lighting reflectors has convinced me that there is an immense field for improvement. There are a great many very good reflectors, but there are a great many more which are in sad need of improvement.

A window lighting installation has been made within the last few months in Cleveland which I think is worthy of attention. There are probably others like it in the country, but I will warrant the number is not large. The store front in question is one

of the converging type, that is, one in which the vestibule is widest at the street side and narrowest at the store end, the windows being set obliquely with regard to the sidewalk. The windows in question are about 7 feet high, about 16 feet in length and 3 feet in depth. The ceiling of each window is divided

Fig. 19.—Too few lighting units. The shadows and non-uniformity of the illumination are evident.

into twenty-four panels, 1 foot by 2. Each one of these panels is recessed in the form of a rectangular box about 1 foot in depth and is painted a flat white. In the center of each one of these boxes is placed a 40-watt bowl frosted tungsten lamp. This makes the energy consumption about 20 watts per square

foot, and with an efficient reflector an illumination intensity of somewhere between 60 and 80 foot-candles might be expected. Actual illuminometer measurements show that the average intensity of illumination is 16.3 foot-candles, measured in a plane 18 inches above the window floor. The noteworthy thing about this window, however, is not the comparative inefficiency of the installation; it is the excellent diffusion of light obtained. There is scarcely a shadow anywhere. Many people who have seen the window state that it is the best lighted window that they ever saw. This praise is certainly not due to high intensity, for there are many windows which are much more brightly lighted. There

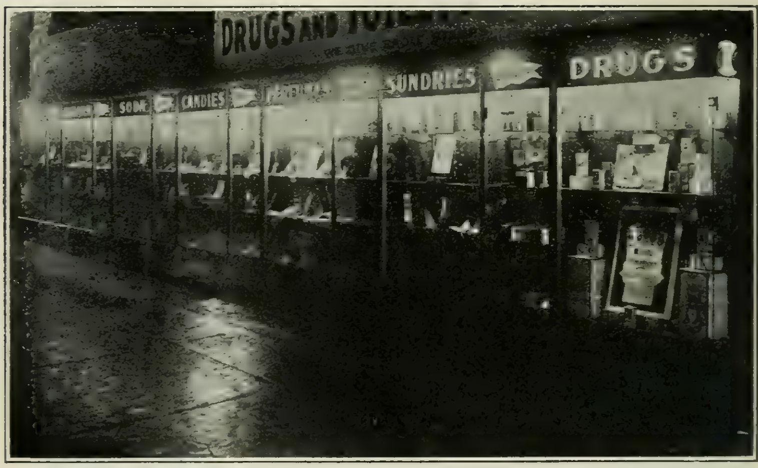


Fig. 20.—A narrow window. It is a difficult problem to light a window of this kind satisfactorily.

are three things which go to make this window the success which it is: first, the window was well and tastily built to begin with; second, the window is always attractively dressed; and third, the light in the window is well diffused and of sufficiently high intensity.

There used to be a great deal of discussion along this line: that there should be a large unit in one corner of a window and that the light units should taper off toward one end or the other, so that shadows in their proper relation would be cast by the various articles on display. Shadows play their part, but my

opinion is that proper contrast between articles on display and the background as well as proper harmony or contrast of articles themselves together with well diffused illumination are of far more importance. If the last two conditions are fulfilled, shadows will take care of themselves.

A high narrow window is nearly always difficult to light. Not only will the window appear brighter at the top than at the bottom, but shadows cast by one article on another are almost unavoidable. Furthermore, such windows are frequently dressed close to the glass making it impossible to light them from above. This difficulty is sometimes obviated by lighting the window from the outside, a generally unsatisfactory method. A more rational method has been to light from the bottom as well as the top, or to divide the window into comparatively narrow vertical panels, and light from the sides of these.

To return to the stage analogy: show windows are built for the express purpose of impressing upon prospective customers the value of the wares on display. The more that idea is impressed upon merchants, the more likely the windows will be valuable. If the stage manager bothered himself a great deal about the amount of energy required for a certain scenic effect, he would probably have few "effects," but he realizes that the "effect" is the all important thing, not the energy he uses to get that effect. On the other hand efficiency should not be overlooked. It is most desirable to get maximum effect at minimum cost. There is no need whatever for one to be wasteful in obtaining a good window. The best of everything is usually cheapest in the end. The merchant who puts in a window lighting installation because it is cheap will regret his action sooner or later, because a poorly made installation is bound to be not satisfactory; but the man who goes into the case thoroughly in the beginning and puts in what is right will have a lasting installation and one which will net full satisfaction.

DISCUSSION.

Mr. P. S. Millar: Referring to the views of the 5 and 10 cent stores, I question if the viewpoint of the proprietors is not divergent from Mr. Henninger's or from that which we would ordinarily adopt. In placing a very powerful flame arc lamp over

the sidewalk in front of a store, a practise which from our viewpoint is to be condemned, the owner of the store wants to advertise the fact that he has that type of store; he wants to make the neighborhood attractive and bright; he wants people to come to that neighborhood, and the kind of people to whom he appeals are those whose esthetic sense does not have to be cultivated. He wants to steer them toward his window and let them view the merchandise displayed. They are looking for bargains, and if he gives them enough light to see in the window he accomplishes his purpose. Hence a big flaming arc lamp is placed in front of the store. I think such merchants are little interested in good window illumination.

Another point that occurred to me as Mr. Henninger was showing the views of window lighting is the difficulty that one encounters in interpreting photographs. Some windows which are successful in practise may be unattractive in photographs. I have in mind an analogous case. One of the most disappointing photographs I ever took was a photograph of an orange tree. The oranges have about the same actinic value as the green leaves. Therefore in the photograph, the oranges were of the same tone as the leaves. An orange tree with a lot of fruit on it is a beautiful object, but in an ordinary photograph it is unattractive.

I rather assume from Mr. Henninger's remarks that as a generality he advocates strong contrasts between background and goods displayed. I question the validity of this assumption for general application. As a casual observer, I think that in the display of goods, particularly of high class goods, pleasing contrasts of a low order, relying on color to some extent for contrast as well as on the reflecting power of the surface, may be quite as much in order as very strong contrasts.

Ten or twelve years ago as one went around the streets of the various cities he would see some effective window lighting, but more frequently he would see some lamps in windows. Usually the difference between the window lighting and the windows with lamps in them was that in the first case trough reflectors were used. The old trough reflectors, perhaps inefficient, often misused, perhaps with insufficient variation in design to meet the

great variables they had to contend with, were so far in advance of other forms of window lighting which prevailed at that time that they deserve a mark of very high esteem in the history of the development of window lighting; and I think they were farther in advance of other lighting methods then in vogue than our best window reflectors for general use are to-day in advance of the trough reflector.

In show window lighting the lesson of concealing light sources was first learned; at any rate, we learned it more completely there than we have learned it in any other class of lighting, and for that reason illuminating engineers must always consider that show window lighting developments have had a good deal of influence on the general practise in lighting.

In testing window lighting consider for a moment the two planes of dress which Mr. Henninger has indicated in one of these diagrams which, as I recall it, in the one case approximated a 45 degree plane and in the other a very deep curve following the contour of the back and bottom of the window. Suppose that one had a white sheet in the window so as to conform to the curve of dress. Then suppose the photometer were placed where the camera has been placed in taking the photographs. The observer might then measure the specific brightness of the sheet throughout its area. That method has been used considerably in studying the distribution of light from headlights, and is a very practicable procedure. If it is not desired to use a sheet in that way, by removing the test plate from the photometer and locating a detached test plate in the window one may measure the specific brightness and obtain corresponding results. The sheet is preferable, however, in that one may study the distribution of light under very favorable terms and if no photometer is available one can design the light distribution very successfully. The use of the photometer for the measure of specific brightness in the entire realm of illumination is a method the advantages of which are only beginning to be appreciated.

MR. J. W. WEIMER: I believe that in a great many cases, it is necessary to use two types of reflectors in a single window, that is, one type of reflector to throw the light back and another type of reflector to throw the light down. I

have found that in numerous cases it was almost necessary to do that. In some cases a window has a shelf. Now, if that window is lighted entirely from above there will be quite a shadow underneath the shelf. It is necessary to use some kind of reflector to through the light back and another reflector to bring the light down on the floor.

The method of trimming windows varies. Some trimmers will trim the windows, building everything up in the back; others will trim a window bringing the goods out towards the front and it is a hard matter to say just what kind of reflector should be used for each case.

There are more windows that can be lighted satisfactorily with the scoop-shaped reflector than with any other type of reflector. This reflector can be used in almost any kind of window. To get the light down just where it should be, the reflector is attached to the transom bar or to the ceiling if the ceiling is at the transom bar.

A merchant wants the lighting installation of his windows arranged in such a manner that it cannot be seen from the outside, practically the same effect that is produced on the stage. A window may be lighted so that people passing by will be attracted by its brightness. Proper lighting in windows will undoubtedly enhance the attractiveness of the window, and thereby increase the sales of the merchant.

Mr. T. M. Aldrich: I think show window lighting should be properly divided into two classes. One class might be termed "Show or Spectacular Lighting," the other "Merchandise Display Lighting."

Show window illumination is installed by a merchant for advertising purposes, and for the satisfactory display of his principal line of goods on sale. The wide-awake merchant usually lays as much stress on the condition of his windows, as regards the amount of space and the way in which it is trimmed and lighted, as he does upon the entire interior of his store.

With the limited amount of space obtainable for show window purposes, usually on account of the high price of frontage on the principal business streets, it therefore becomes imperative for

the merchant to display his goods to the best advantage at all times.

Show windows are primarily used for two purposes: the first and most important purpose is to attract the attention of the public in passing by his establishment; the second purpose (after the public's attention has been attracted to his window display) is to be able to display to the best advantage the principal line of goods on sale, their intrinsic value and their cheapness in price, in order to so interest the public that they will become a purchaser.

Show or Spectacular Lighting.—In this class comes the small and medium sized stores which usually sell a cheaper line of merchandise, and which use "show lighting" as an effective means to get business. Under this class of show window illumination are to be found the most glaring examples of artificial lighting. The number of lamps, and the amount of current used, is not considered of importance so long as a blaze of glory is furnished by the windows. The owner of a window of this sort obviously seeks to attract the public to his window and after once getting them this far, he counts on a fair percentage of the public entering his store and purchasing merchandise.

Show windows of this class are lighted most brilliantly and usually by one of the following methods, which are commonly used:

In the majority of installations of this order, bare lamps are usually installed in large numbers, and in most cases within the line of vision, thus causing the public great discomfort in viewing the goods on display, and defeating the very purpose which they are striving to accomplish. These merchants believe in buying and furnishing glare for their show windows instead of illumination. Their style of lighting consists, in the majority of cases, of either one of these methods.

Chandeliers with high candle-power units are often placed in the center of the window, and frequently wall brackets are added; the effect is to compel the public to take particular notice of the fixtures instead of the goods on display.

Installations of great numbers of lamps either bare or with clear prismatic reflectors on the ceiling of the window, if it is

not high, are very distracting to one looking into the window. Nickel-plated pipes, with bare lamps, usually 25 or 40-watt sizes, are installed in a vertical position, in the front corners of the windows, with lamps usually in a horizontal position; thus furnishing a brilliant source of illumination outlining the shape of the window. Quite frequently lamps are intsalled in this position on strips of wooden molding.

The effect of such lighting is for attractive purposes only, and is very extravagant and inefficient. In all of these intensely illuminated windows, the light sources are so intense, as to cause positive discomfort to the person viewing the merchandise on display. The amount of money spent so lavishly is beyond all reason, and unnecessary. In many installations by these methods, the amount of current used could easily be reduced seventy-five per cent. by the use of scientifically designed window reflectors properly placed.

Merchandise Display Lighting is a term that may be applied to those windows that are illuminated in accordance with engineering and scientific ideas. This class of lighting is most generally used by the larger and better class of stores, where illumination is sought to display goods to best advantage, and with the least ocular discomfort to the public. This is usually accomplished most effectively by the installation of concealed light sources. The better class of merchant believes in buying and furnishing his windows with effective illumination, and not glare.

The trend nowadays is very decidedly toward concealed light sources, with its attending attractiveness of illumination thus furnished so effectively. Recent practise has shown conclusively the necessity of installing show window lights in either one or two locations, if the merchandise on display is to be seen at its best advantage. They should be preferably placed in the front top corner of the window, either on the ceiling, if the window is high, or on the transom bar if the window is of medium height. Where reflectors, either in the form of a trough or single units, are placed in this part of the window, the light can be directed or thrown down onto the goods on display at the proper angle to bring out the merchandise in detail, and with the right perspective. The other scheme is to provide the window with the

desired intensity, with reflectors placed in the top of the ceiling, and the lamps concealed from view; an effective illumination is thus furnished.

In merchandise display lighting, the windows are trimmed on a much higher order than in the cheaper class stores. For instance, in cheaper stores there is evident a high order of contrast between the background and the goods on display, while in the better class of stores, the reverse is to be found; a low order of contrast, or more complete harmony of colors of both merchandise and background. With a low order of contrast and with concealed light sources properly placed, the resultant effects are all that can be desired in show window displays. The most attractive show windows of the country are accomplished along these lines.

Under this type of window lighting, the reflectors used most are of the following design:

Reflectors.—Trough reflectors, constructed of metal and lined with either white opal glass or corrugated mirrored glass (quick silver backing) are used frequently. The white opal glass lining is of a more permanent nature as a reflecting surface (though less efficient) than the mirrored glass surface. The mirrored glass lining has a higher initial efficiency than the white opal lining, but after continued use, the reflecting surface gradually turns brown and begins to peel off at the edges of the different segments lining the trough. This is caused by the action of the air and heat on the quick-silver backing. Trough reflectors, though quite extensively used, are much less efficient than other types of individual reflectors. Their principal advantage is in their cheapness in price, and the ease with which they are installed. Their disadvantage is their great waste of light which is reflected into the upper portion and toward the ends of the window, where it is not needed. This is caused by the reflector not entirely enclosing the lamp, and the exposing of a considerable portion of the filament directly toward the ceiling and top portion of the window. Considerable light is thrown down at an angle which strikes the sidewalk and is thus lost for practical purposes.

Various types of metal reflectors, having either a matte alumi-

num or porcelain enamel reflecting surface, have been used somewhat, but are not as efficient as either the clear prismatic or the silvered glass reflectors.

Opal glassware is sometimes used where the esthetic considerations are of more importance than efficiency.

Steel cone-shaped reflectors lined with mirrored glass strips have been used for many years, for window lighting, and are fairly efficient while new, but are not permanent in nature or efficiency, and are a nuisance to keep clean on account of the many joints in the glass strips as inserted.

For small sized show windows, having little depth and width, and with low ceilings, the tubular form of lamp is used to good advantage. These lamps are made in the form of a single straight filament, approximately twelve inches in length and either of carbon or tungsten. They are usually installed either in the upper front corner or in a vertical position at the sides of the window. On account of their small size and little space required for their use, they can be installed with good results in this type of window.

The clear prismatic reflector and the silvered glass reflector which are the most efficient show window reflectors on the market to-day deserve mention. The advantages of the clear prismatic reflector are its cheapness, and its scientific design, whereby the largest portion of light reflected is thrown down onto the goods on display with good results. Its disadvantage is the necessity of removal (on account of its prisms) for cleaning at frequent intervals; also, on account of its being translucent in form, there is dissipated a considerable amount of light in the upper part of the window, and on the ceiling, where it is unnecessary and of no use to the merchant.

Probably the most efficient reflector, designed primarily for show window illumination, is made of glass, with a silver backing and of varying designs for different sized windows. This reflector is opaque, and therefore no light is lost in the upper part of the window; the reflector entirely encloses the lamp and distributes the reflected light down at the most effective angle for the illumination of the goods on display. This reflector is more

expensive than the other types mentioned, but has the highest efficiency of all.

The trough reflectors, as well as the various styles described above, should be placed invariably in the upper front corner of the window, or on the front transom bar of the show window, in order to afford effective illumination in an economical manner.

Specular Reflection.—There is one point in show window illumination which has been overlooked by the average merchant, and which should be corrected. I refer to the specular reflection so noticeable in the majority of high grade windows throughout the country. The custom is to back the rear of most windows tc a height of 6 feet to 8 feet with panelled woodwork, and from this height to the ceiling to insert glass panels, allowing for entrance of light in the daytime. At night, when the window is lighted, the images of the lamps and reflectors are shown in relief on the glass panels; this reflection spoils the effectiveness of the display, and is decidedly objectionable. This objection can be readily corrected by hanging a white Holland shade inside the show window and in front of the glass panels, which will not only effectively eliminate the specular reflection but will help the illumination as well.

If the background is trimmed in other than a white color, the shade can be made to match, and thus obtain harmony throughout. These curtains have been installed by some of the better stores and no doubt will be used by the majority of merchants as soon as it is brought to their attention.

Lamps.—The tungsten lamp is almost universally used for show window lighting, on account of its high efficiency, color value, and long life. These characteristics make this type of illuminant valuable to the merchant for window lighting.

There are a few cases, however, in some of the higher class stores, where the carbon lamp is still adhered to. This is done on account of the inherent color value of this type of lamp. The illumination as furnished from the carbon lamp gives a soft, mellow light, and even at a sacrifice in efficiency, is used by the largest retail merchants in the United States for their show window illumination. The color of the light is very acceptable where a low order of contrast in trimming is carried out, and where com-

plete harmony in the colors of the background trimmings and merchandise on display is desired. The type of lamp used in these installations is what is known as the "reflector lamp" and is made in the 40 and 60-watt sizes, having the upper half of the lamp silvered so as to reflect all of the light from the filament down onto the goods on display. No other reflectors are necessary for use with this lamp on account of the top half being opaque.

Alternate Lighting.—The alternate system of show window lighting has been installed with economic and satisfactory results by some merchants. There are some very good points in favor of this system which if it is installed properly in a medium sized window, will repay the merchant for the extra installation cost necessary. This system consists of one-half of the lights being on a separate circuit and switching from the other half. By this method but one-half of the total number of lamps installed is utilized when the window is used for the display of white goods because, of course, white goods require less than half the illumination necessary for dark goods. Besides, showing the goods on display to better advantage, there is effected a considerable saving in current. This system should be adopted more universally by the merchant who has limited show window space, and where frequent trimmings are therefore necessary.

Progress in Window Lighting.—Many different types of illuminants and reflectors have been used during the last twenty years for show window lighting, and I can remember that the average installation of show window lighting in 1890 or 22 years ago consisted of either gas jets or bare incandescent lamps suspended on drop cords in the front part of the window. Windows in those days were not as deep as the windows of to-day.

The first reflectors used, were of the flat tin type, which were followed by the flat white opal reflector; then came the cone shape, in the form of green glass with white inner surface. The mirrored glass cone was also used about this time, being made of small sections of mirrored glass laid in a tin cone stamping. These mirrored cone reflectors have been more universally used down to recent years than all of the other types combined. Their disadvantages is that they invariably turn brown after continued use

and become poor reflecting surfaces. This defect results on account of the use of a quick silver backing instead of a pure silver one.

Later on the gas arc was used. The Nernst lamp has also been used in many installations. With the advent of the tungsten lamp, the illumination has been increased to such extent as to become decidedly objectionable to the public in viewing the goods on display, and the lamps and various types of glassware used are more prominent than the merchandise displayed. The purpose desired by the merchant in displaying his goods, is therefore not accomplished.

The idea for many years was to install as large a light source as was obtainable, with the belief that perfect illumination was being obtained. It is unnecessary to elaborate on this fallacy, as the merchant to-day is becoming educated in the proper use of the light sources, and is concealing his lamps in scientifically designed reflectors of high efficiency, so that he is obtaining satisfactory and effective results with the least expenditure of current. He is purchasing what he requires, illumination and not glare, in the form of large sized units, which are blinding to the public and unquestionably detract from the goods on display.

Rational show window illumination is on the increase, and the benefits to be derived from it are now being appreciated by the wide-awake merchant.

Mr. Augustus D. Curtis: I want to make this somewhat startling statement: there is probably a greater waste by the average merchant in illuminating his windows than in any other department of his store. This waste, I think, might be found to average 50 per cent. If the same waste existed in the other departments the average merchant wouldn't last six months. I think that my statement will be substantiated by observation. There is a great field for improvement in 80 per cent. of the stores.

Mr. Harvey B. Wheeler: The distribution curves of the various window reflectors taken through a plane perpendicular to the window and axis of the lamp do not illustrate the exact distribution of light in a window. This is even more true with non-symetrical reflectors. A curve taken with several lights

burning perpendicular to the window, midway between two reflectors, would be very interesting and demonstrate clearly the merits of the style of reflector.

Mr. J. G. Henninger: It would be interesting. My primary idea in figuring up those curves was to see in general what would be the cross-section, you might say, of the light coming down on the ground that it would be desirable to get uniform illumination on the plane of dress. I wanted to compare commercial reflectors on the market to-day. Another thing that is obvious I think from the cross-section is that the total light of the lamp may be confined within a vertical angle of 90 degrees or less. Any light above that or outside of it is usually dead loss because it will not be returned to the goods. That suggestion you make of running the curve in the plane of the window would be very interesting. With the majority of window light reflectors we have at the present time probably you will find the intensity higher than desirable in some portions and lower in other portions of the curves, but on the whole I think comparing the theoretical curves with the actual curves we can very easily pick out a type of reflector to fit pretty nearly every case very nicely. One reflector will not fit every case.

Mr. Harvey B. Wheeler: I think that when these curves are made we will find that the illumination around the dress circle will not be in proportion probably to the way the curves show up there when you plot the curves to the vertical.

Mr. J. G. Henninger: You mean the vertical section will not be what is shown there?

Mr. Wheeler: Yes.

Mr. Albert Scheible: In judging this subject broadly it seems to me that we ought to pay a little attention to the psychology of lighting. Most of us when we asked to follow the band not only want to listen to the music but also want to see the band; and the evolution in lighting has been the same way. People not only want to see what is lighted but to a certain extent may want to see where the light is.

The first show windows I helped to light in Chicago were in a jewelry store down on Wabash Avenue. They were lighted by means of a sixty-watt series incandescent lamps hung from

drop cords (cotton covered lamp cord), on a 9.6 ampere arc circuit. That was before the days of our present underwriters' regulations. Each had a ten-inch opal "flat cone" reflector over it which to-day would be called very hideous; yet as a lighting proposition in those days it was a success, because people would readily come from the other side of the street to see those bright lights and look at what was under them.

Mr. Henninger showed one florist's window which had the lights exposed with, if I remember right, prisms and possibly colored globe effects. Occasionally attractive effects of that sort have been produced. Hence I doubt whether the conclusion that under all conditions the light should be obscured is warranted.

May I ask Mr. Henninger if any color screen or ray filter was used in taking his pictures?

Mr. J. G. Henninger: No, just direct exposure, about eight minutes.

Mr. Albert Scheible: Then in some cases the pictured contrast between the background and the articles displayed might not be true to what was actually seen by the eye?

Mr. J. G. Henninger: That is possible, but for the most part the pictures show up pretty well the effect that was meant. I personally went around and picked out the windows.

Mr. Albert Scheible: There are two classes of window lighting regarding which I notice no reference; one is the use of straight filament tubular lamps with reflectors behind them, and the other is the use of gas arcs placed outside of show windows but close to them with a reflecting hood directing the light into the windows.

Mr. J. G. Henninger: I hadn't intended to take up any of what you might call specific forms of window lighting, but the straight filament lamp has been used very successfully indeed. As for the placing of gas arcs out in from of the window, I don't think as good an effect can be obtained with large units placed outside a window as with the use of smaller units placed inside. I don't see how the glare reflected from the window can be avoided. The lamps can be covered with hoods, but the more they are covered the more the view of the window is obstructed.

Of course, they might be placed high but I have never seen an installation of that kind.

Mr. J. R. Cravath: Mr. Scheible enquired as to whether there were not some places where it was desirable to show the lamps, and that reminded me of a story some illumination salesman told me about going into some owner of a cheap clothing store in New York where they had lamps all around the borders of the windows. He said, "Why, don't you know you have got those lamps so they dazzle people and they can't see the goods at all?" The owner replied, "What do you take me for; do you think I want them to see those goods." He wanted something to attract the crowd but he didn't want them to see the goods too well. That undoubtedly applies to a certain class of stores.

There is one point to which I would like to call attention and that is it is very difficult to make a good showing with an improper shape of window. It is almost impossible to produce good effects with a very shallow window in which the lamps must be placed at considerable height. There are concentrating reflectors that are designed to light that class of windows but the results are always inferior to those that are obtained with rather deep windows where the lamps are not very far above the top of the window. The reason for it is very simple: in a shallow window the tendency is to crowd the goods, and the goods in the front of the window are in such position that they almost cast shadows on themselves; and no matter how close to the plate glass the lamps are placed, there is bound to be very low illumination on the upright goods in the window front because there is very low vertical illumination at that point. With the deeper windows the light falls on the goods more nearly at a normal angle and, therefore, the effect is much better.

The question of diffusion and shadow are things that go hand in hand. If there is good diffusion there is an absence of bad shadows; and the effect is pleasing. I believe with Mr. Henninger that there must be a considerable number of units scattered along the front of the window in order to get light falling on the different objects from a good many different directions and make them stand out advantageously.

Another great trouble with some window trimmers is they try

to get too much in a window; they crowd things together too much and put tall goods near the front of the window where they cast shadows on themselves.

As to the point raised about the photometric curves of different reflectors: it is of course true that no curve which is taken simply in one plane of a non-symmetrical reflector will tell the whole story of what the reflector may be. There may be points in that plane that are abnormally high or abnormally low. The correct way to test any window reflector is to equip a window with a number of them just as one would do in practise and then test the illumination on the line of trim of that window. That is a thing that has very seldom been done, but it is a thing that ought to be done more in the future and I hope that we will have more information about it very shortly.

A LABORATORY SYSTEM FOR TESTING ELECTRIC INCANDESCENT LAMPS.*

BY W. M. SKIFF.

This paper outlines a system devised by the engineering department of the National Electric Lamp Association for testing electric incandescent lamps in the laboratories of that organization.

In planning work of this character three factors must be considered, viz., quality, cost and service. Any one or two of these may be sacrificed for the sake of the third. For example, the quality of the work may be of the best but the cost high and the service rendered poor. Similarly a piece of work may be done well and at low cost but at the expense of poor service. Then again it is possible to get excellent service and a high quality of work but at a prohibitive cost, etc. Ordinarily quality is the first requisite to be considered, but the final goal is the rendering of the best service by turning out the highest quality of work at minimum cost or, to put it more briefly, the best work, quick and cheap.

A considerable portion of the work in the aforementioned laboratories is being done by automatic devices of all kinds; but the successful operation of these machines is dependent upon human skill—and human beings are liable to make mistakes of a more or less far-reaching character. Similarly in the working out of any system for the performance or handling of certain work there is always liability of some individual doing the wrong thing at the wrong time and only that system of operation will prove effective from every standpoint, which provides checks and cross checks, all of which aim to reduce personal errors to a minimum by detecting any errors made and providing means for eliminating their recurrence.

The need of such a system is obvious. For example, one relies on a foot rule for the reason that at any time he wish he can have its calibration verified and satisfy himself as to its correctness. Similarly if a system of performing a certain portion

* A paper read before a meeting of the New York section of the Illuminating Engineering Society, April 11, 1912.

of work is so surrounded with a method of detecting any possible error, tracing it to its source, determining who made it, why or how they made it, possibilities of its recurrence, means of eliminating a recurrence, and if adequate records are maintained of all these facts, the liability of error will be reduced to a minimum.

A point to be borne constantly in mind in laboratory work is that an individual's definition of required accuracy is liable to change. One may to-day consider that working within limits of ± 1 per cent. is sufficiently accurate but possibly in another year due to perfection of apparatus and methods an accuracy of ± ½ per cent. is just as easily attained.

The scheme which has been worked out in the engineering department of the National Electric Lamp Association to obtain the greatest possible accuracy in laboratory work and eliminate as far as possible the personal equation is to pit one operator against another and from the results obtained at each step draw conclusions as to the correct results. There is of course a possibility that two operators, even though they are unacquainted with the results of each other, may make the same error, but the chances of this happening are reduced by additional checks made by others.

Incandescent electric lamps which are received for test are first classed as regular and special. Regular tests comprise those which are carried out under standard instructions uniformly applicable to that class of lamps. Special tests include those which are carried out under special instructions for each test which usually vary widely in nature and purpose. The majority of regular tests are made to determine the candle-power maintenance and life of lamps at their commercial rated efficiency and while the purpose of special tests may be different the vital steps in each process are the same.

The work involved in the lamp testing is shown diagrammatically in fig. 1.

1. *Receiving*: Upon receipt of the test lamps, written information concerning them is placed with the lamps when the shipment is opened and never leaves them until the lamps have been provided with identification labels No. 2. After inspecting

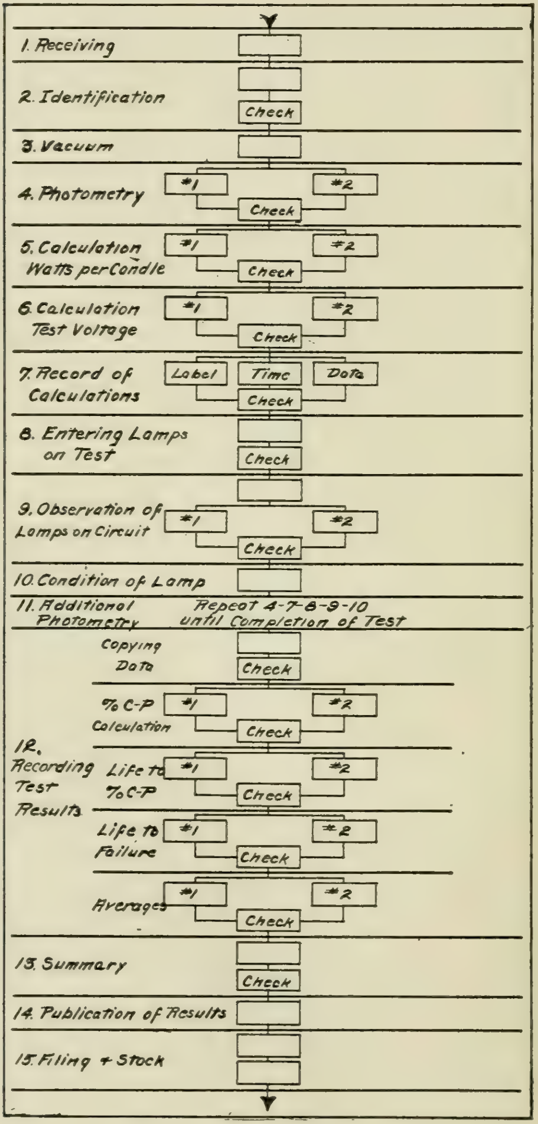


Fig. 1.—Progress of lamp life tests.

and checking the lamps against orders and shipping memoranda, receiving slips are made out and the standing order number assigned to the lot. The mechanical condition of the lamps is

then determined and any breakages, shortages, or irregularities noted.

2. *Identification*: For the positive identification of all lamps, each lot is assigned a test number and each lamp an indi-

Form 51-9—[illegible]

INSTRUCTIONS FOR SPECIAL TEST

COPY TO BE MAILED TO ENGINEERING DEPARTMENT

ORIGINAL

In Correspondence Please Refer to Ins. Sheet 3702

191

ENGINEERING DEPARTMENT

Testing Section lamps are being forwarded to you via

From Mfgd. by Factory No.

Test Designation					
Quantity					
Class					
Watts					
Volts					
C-P.					
Filament Material					
Filament Form					
No. of Loops					
Hook Material					
Bulb Size					

Method by which tests should be made if other than regular

Please send results to

Signed

BELOW TO BE FILLED IN BY ENGINEERING DEPARTMENT

No. 191

The above shipment has been received by

with lamps in good condition and lamps broken on receipt 51-51

we expect to be able to place lamps on test 191

Please refer to Eng. Dept. Order No. Test No. 51-3

In correspondence concerning above test

ENGINEERING DEPARTMENT

Fig. 2.—Form used for instructions for special lamp tests.

vidual number. These assignments are recorded on labels placed on the lamps and the same identification placed on data cards, time cards and instruction sheets. The data cards give a full description of the lamps and complete instructions for carry-

ing out the test. These cards are made up from information obtained jointly from standard instructions, special instructions (fig. 2) and from an inspection of the lamps. Time cards bearing the same identification numbers are for the use of recording the time intervals of burning on life racks. After making out these cards the whole is verified by an inspector of tests, whose duty it is to be thoroughly conversant with all testing technicalities. A report of verification is recorded on the test card and entries made on the instruction sheet and a tracer card, which facilitate the tracing of the test to completion.

3. *Vacuum*: After proper identification precautions have been taken the lamps are subjected to a vacuum test. A record

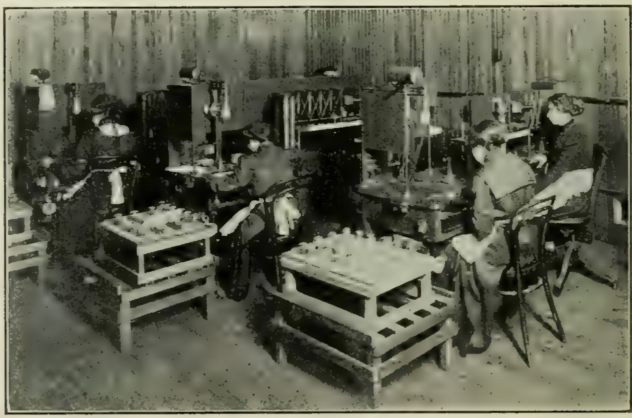


Fig. 3.—Lamp life testing photometer room.

of the condition of the vacuum and the name of the individual making the test are then noted on the data card.

4. *Photometry*: In the performance of photometric operations the accuracy of the work depends both on mechanical devices and on the judgment of the operators; both the mechanical devices and the operators are checked as stated further on in this paper.

Nothing is saved in the way of equipment which will tend to promote the accuracy of the work. Lummer-Brodhun contrast screens are used on all life test photometers. The voltmeters used are of the standard laboratory type with scales accurately

readable to 10ths of a volt. The ammeters can be read accurately to 1,000ths of an ampere. All meters are calibrated at regular intervals of fifteen days and accurate records (figs. 5 and 6) kept of each calibration enabling a change in characteristic curve to be readily detected.

If at any time there is any possible doubt as to the accuracy of the meters they are rechecked at once. Meters are calibrated (see fig. 4) through potentiometers from standard cells from the Bureau of Standards. Accurate records are kept as to the date of arrival of each standard cell, number of minutes and by

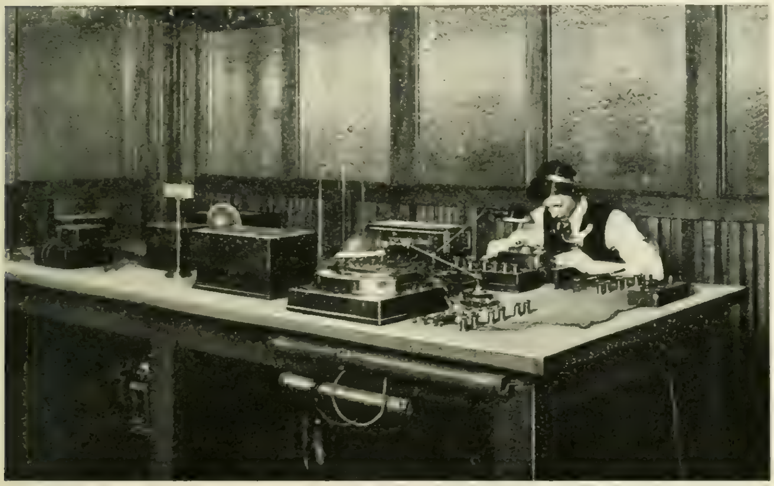


Fig. 4.—Calibrating room.

whom used, also conditions under which it is operated. As an additional precaution the voltmeters on various photometers used for testing work are frequently paralleled and calibrations made to determine if each meter is in check with every other at different points on the scale.

On the photometer heads devices are provided by means of which the operator sets both the working standard and the lamp to be measured at such a height that a horizontal line drawn from the center of the filament of one lamp to the center of filament of the other will pass through the center of the contrast screen. Rotary mercury contacts, of an especially dust proof design, are

installed on the photometer heads and effectively avoid voltage drop, as is shown by frequent verification tests.

The checking standards used are rechecked against the Bureau of Standards standard lamps on a precision photometer every fifteen days and an accurate record kept of each such re-check. Additional checks are made at any time when the reading of lamps

CALIBRATION OF

.... NO. ....

	STANDARD		AVE. READING	CORRECT READING	COR-RECTION
	UP	DOWN			

..RECEIVED FROM ....

....

..CALIBRATED.................BY ....

..RETURNED TO ....

....

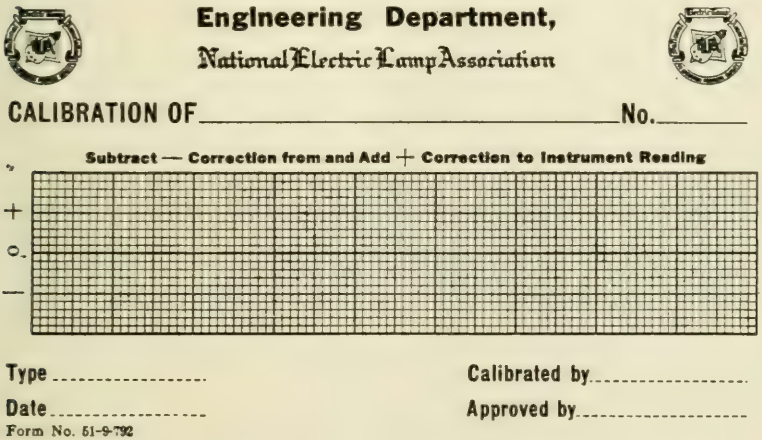
Fig. 5.—Form for recording the calibration of meters.

is in any way questioned. Four times each day each photometer and its spot reading operator is checked for accuracy. The method of checking is as follows:

The person in charge of the photometric work reads the instruments while measuring standard lamps from the Bureau of Standards. On each standard five readings are taken, the average of which must compare with the standardized reading of the

lamp. The regular meter reader then reads the meters while two more secondary standards are checked by five readings. If everything checks the operators of machines are ready to read the lamps for test. As an additional check two standards are read just prior to the measurements of every tray of lamps.

Every lamp measured initially and at every subsequent interval, is measured on two photometers by different operators and the results of these two measurements are recorded on the data cards together with the designation indicating both operators and the machines used. Neither spot reading operator is acquainted with the results obtained by the other. The results are compared in per cent. candle-power differences and in case



Engineering Department,

National Electric Lamp Association

CALIBRATION OF________________________No.______

Subtract — Correction from and Add + Correction to Instrument Reading

Type.................. Calibrated by..................

Date.................. Approved by..................

Form No. 51-9-792

Fig. 6.—Form for recording corrections to meters.

any measurement differs by more than a fixed per cent. of accuracy the lamp is recorded by the checker on a checking slip, and without reference to operators' readings a sufficient number of readings is taken to establish the rating. When a lamp has been re-checked a record is made on the card showing that the checking has taken place. The correct reading then entered becomes verified data. A comparison of the readings taken on the two machines at any interval includes a comparison with the reading taken at the previous interval so that in case the performance of the lamp appears extraordinary the true value at the last interval of measurement may be established. As a still

further check on the photometer operators, lamps on which the photometers have previously agreed are sent in for measurement at any time each day by the checker.

The current for photometric work is obtained from storage batteries of ample size, which are kept in the best possible condition. Accurate records are maintained as to the condition of each cell (figs. 7 and 8), conditions of charge and discharge, etc. To prevent possible voltage variations no more than one photometer is connected on a battery circuit at one time.

SPECIFIC GRAVITY
OF
INDIVIDUAL CELLS

DATE			DATE			DATE			DATE		
CELL No.	SP. GR.	TEMP.	CELL No.	SP. GR.	TEMP.	CELL No.	SP. GR.	TEMP	CELL No.	SP. GR.	TEMP.
1			2			3			4		
5			6			7			8		
9			10			11			12		
13			14			15			16		
17			18			19			20		
21			22			23			24		
25			26			27			28		
29			30			31			32		
33			34			35			36		
37			38			39			40		
41			42			43			44		
45			46			47			48		
49			50			51			52		
53			54			55			56		
57			58			59			60		
61			62			63			64		
65			66			67			68		

Fig. 7.—Form for recording condition of cells.

5. *Calculation of Watts-per-Candle*: From the initial rating of the lamp itself is made the calculation of watts-per-candle. This computation is made independently by two operators and an absolute check is required.

6. *Calculation of Test Voltage*: From the watts-per-candle and voltage at the initial measurement, the test voltage is computed independently by two operators and an exact agreement required.

7. *Record of Calculation*: The calculations are then transcribed from the data card and the regular card to the test voltage label on the lamp. This transcription is verified independently by another operator.

8. *Entering Lamps on Test*: The next step is the placing of lamps on the test voltages ascribed to them. As much depends upon the accuracy with which this voltage is maintained a description of the generating room may be properly included at this point.

Power enters the building at 2,100 volts and operates a syn-

MONTHLY BATTERY REPORT

CHARGING DATA ON BATTERY NO. CAPACITY A. H. PILOT CELL NO.

DATE 191						DATE 191					DATE 191					DATE 191				
DISCHARGE A. H						DISCHARGE A. H					DISCHARGE A. H					DISCHARGE A. H				
CHARGE A. H						CHARGE A. H					CHARGE A. H					CHARGE A. H				
CHARGING CURRENT AMP						CHARGING CURRENT AMP					CHARGING CURRENT AMP					CHARGING CURRENT AMP				
TIME	SP. GR.	VOLTAGE	CAD. +	CAD. -	TEMP	SP. GR.	VOLTAGE	CAD. +	CAD. -	TEMP	SP. GR.	VOLTAGE	CAD. +	CAD. -	TEMP	SP. GR.	VOLTAGE	CAD. +	CAD. -	TEMP
1ST HOUR																				
2ND ..																				
3RD ..																				
4TH ..																				
5TH ..																				
6TH ..																				
7TH ..																				
8TH ..																				
9TH ..																				
10TH ..																				
11TH ..																				
12TH ..																				
CHARGED BY						CHARGED BY					CHARGED BY					CHARGED BY				

Fig. 8.—Obverse side of form shown in fig. 7 used as monthly battery report.

chronous motor direct connected to a 200 kw. single phase alternating current 120-volt generator. This machine is so chosen that with an approach to full load on the life test racks the machine operates at full load, which range permits of the closest voltage regulation. The voltage is controlled by a Tirrell regulator from the center of distribution. Protection is provided from over voltage by meter controlled breaks. At the switch-board a recording voltmeter is used to indicate the time at which the regular circuit is turned on or off. For the purpose of indicating voltage regulation a laboratory standard indicating meter

with a specially designed scale, which can be read with great accuracy, is installed. This meter is calibrated against a potentiometer every day and readings are made from it hourly by the men in charge of the power equipment. A report is made on these readings showing the voltage at each hour, a maximum, minimum and an average for each twenty-four hours. As an additional check the meter is observed at frequent intervals without the knowledge of the generator operator and a record kept of such checks.

The primary voltage of 120 volts is stepped up or down at the life racks (fig. 11) by means of auto transformers of ¾ kw.

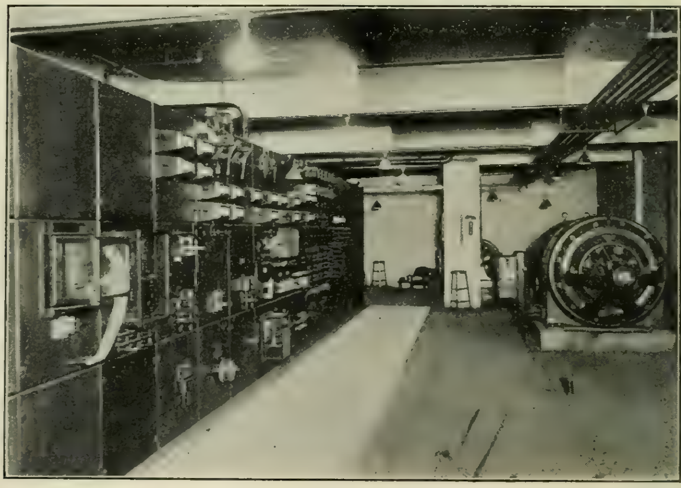


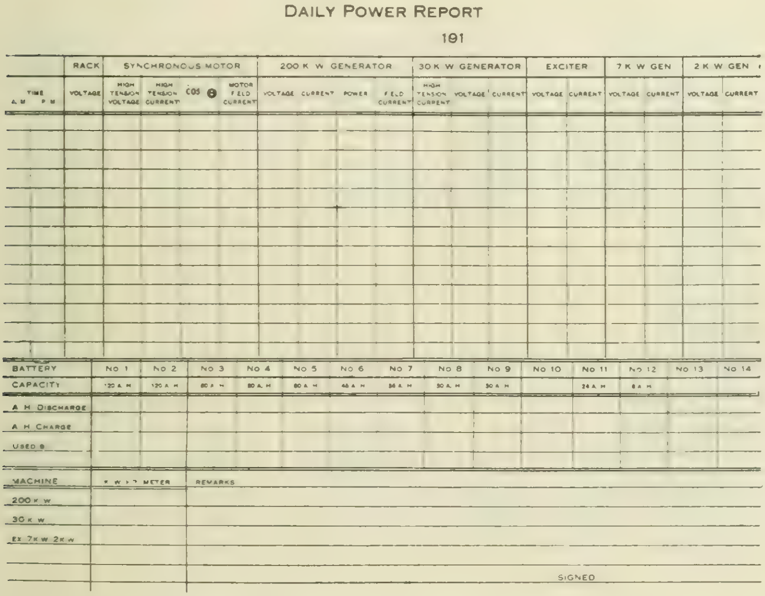
Fig. 9.—Lamp life testing generating room.

capacity to voltages above and below the bus voltage. The secondaries of the auto transformers are connected by means of soldered contacts to brass channels on each of which are installed five sockets. No transformer is installed until after it has passed a complete acceptance test. As a further precaution against possible imperfect contacts, voltmeter tests are made at stated intervals on the circuits of each transformer and a record of each such test is maintained.

The lamps are installed in the sockets according to the test voltages, recorded on each lamp; the time at which lamps go on

test is recorded on two identification cards and at the same time the schedule time at which they are to be removed for measurement is entered. One identification card is sent to the lamp inspector while the other is filed for the information of the rack operator, cards being so filed that the schedule time recorded on each card is self-indexing.

9. *Observation of lamps on Circuit*: The racks are continually under the observation of the rack-room operator and a



DAILY POWER REPORT

191

	RACK	SYNCHRONOUS MOTOR				200 K W GENERATOR				30 K W GENERATOR			EXCITER		7 K W GEN		2 K W GEN	
TIME A M P M	VOLTAGE	HIGH TENSION VOLTAGE	HIGH TENSION CURRENT	COS θ	MOTOR FIELD CURRENT	VOLTAGE	CURRENT	POWER	FIELD CURRENT	HIGH TENSION CURRENT	VOLTAGE	CURRENT	VOLTAGE	CURRENT	VOLTAGE	CURRENT	VOLTAGE	CURRENT

BATTERY	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11	No 12	No 13	No 14
CAPACITY	120 A H	120 A H	80 A H	80 A H	80 A H	46 A H	36 A H	30 A H	30 A H		24 A H	8 A H		
A H DISCHARGE														
A H CHARGE														
USED θ														

MACHINE	K W H METER	REMARKS
200 K W		
30 K W		
EX 7 K W 2 K W		
		SIGNED

Fig. 10.—Form used for daily power report.

half hour inspection is made regularly for burn-outs. Every two hours a close inspection is made of each lamp on test to determine any irregularities or vital defects.

When a lamp is found to have failed on test it is removed from the racks and a label is placed upon it. On the label is recorded the schedule time of failure, the nature of the defect and the inspector's designation. Elapsed time on test is computed by the rack inspector and a record of the same is placed on the identification card and on a burn-out report (fig. 12). The lamps are then delivered to the lamp inspector who verifies the cause of

failure and, by means of the duplicate identification card in his possession, recalculates the elapsed time, thus checking the figures of the rack inspector.

The rack operator makes an inspection every second hour to determine if each lamp is burning on the voltage for which it is intended and in addition to this another operator, who is in no way responsible for rack room work, makes a daily inspection of all lamps on the test racks for the same purpose.

From the foregoing description it will be observed that every

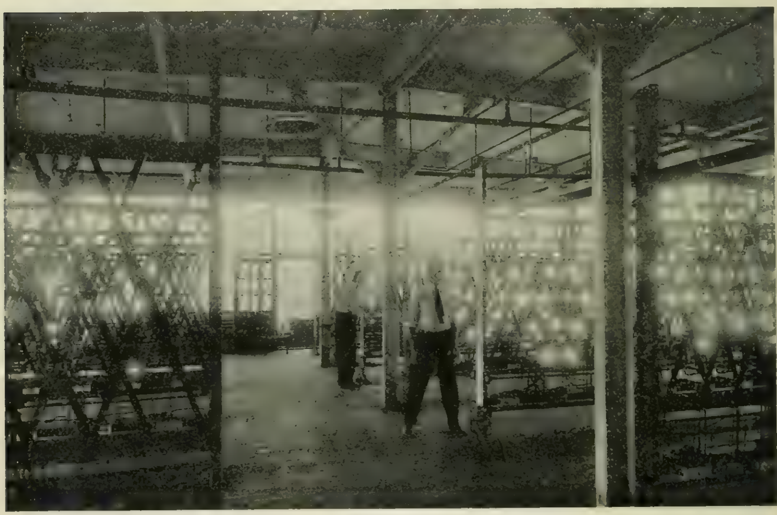


Fig. 11.—Lamp life test room.

operation of a vital nature has been checked up to the point at which the final record begins. It will be readily seen also that the possibility of instrument error or errors of mechanical devices as well as the possibility of personal errors has been reduced to a minimum.

10. *Condition of Lamps*: After burning a certain period on life tests, the lamps are returned to the photometer room and photometered. During this process the lamps have to pass through several different operators' hands and in order to fix the responsibility for breakages, errors, etc., each operator before he will accept the lamps from another operator is required to

verify for himself the condition of the lamps. By this method any error on the part of an employee is readily detected. The lamps are delivered by the rack-room inspector to the operator in charge of the general clearance room. The clearance room operator delivers the lamp to the chief inspector or to the photometer room operator as the case may be who, upon return of the lamps which have been photometered, delivers the lamps to the rack inspector. Each time that the lamps change hands they are inspected.

11. *Additional Photometry*: After each period of burning the process carried out on each lot of lamps is essentially the same as described under initial photometry, record of calculation, entering lamps on test, observation of lamps on circuit and condition of lamps.

BURN-OUT REPORT

SHEET No.________

________191____

CLASS	TEST No.	LAMP No.	TOTAL HOURS TO B. O.	INSPECTION MARKS	SCHEDULE TIME OF B. O.	MFG. BY	WATTS	VOLTS

Fig. 12.—Form for recording lamp failures during a test.

12. *Recording Test Results*: Up to this time all the information concerning the lamp has been confined to one test data card. This data card contains records by which each item of information can be traced to its source and from this card it is possible to make any manner of report concerning the performance of a lamp. The most common report required is one in which the hours of life to some predetermined percentage of initial candle-power and life to failure are the results desired. Standard forms are provided which permit this information to be transcribed in the same way in which it appears on the test data card. These forms (fig. 13) are made of tracing paper and the records thereon are made in black India ink to facilitate blue printing. All transcribed work is verified by a second operator

and such records made that the original work and the checking can be traced to the respective operators.

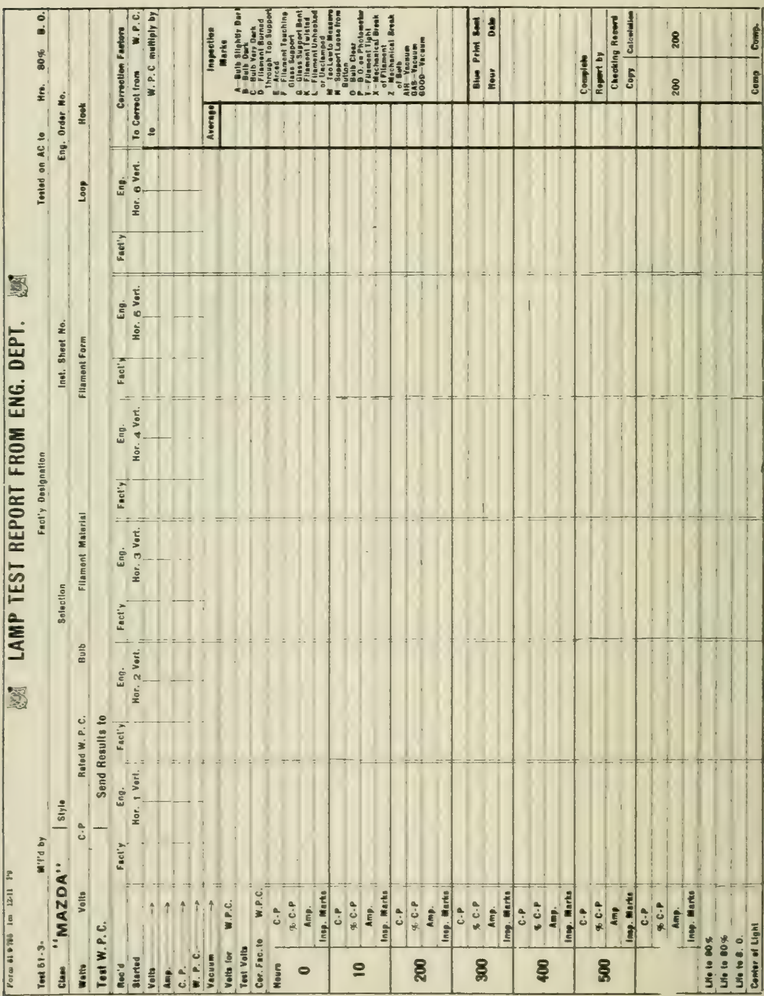


Fig. 13.—Form used in recording lamp test data.

All calculations such as calculation of per cent. candle-power, life to a predetermined per cent. candle-power, life to failure and average results are made by one operator and duplicated in-

dependently by a second operator and an exact agreement is required.

13. *Summary of Results*: When the summary of this report is desired a preliminary report is first drawn up by one operator and the figures and results checked against the original data by a second. Should a record be made by some other method than blue printing, this final report is compared with a preliminary report for verification.

14. *Publication of Results*: The results of life tests are taken from the original test sheets by blue printing. This test sheet contains all the data regarding the lamps, not only as to their

Form [illegible]

INDIVIDUAL ERROR REPORT

FROM________________ WEEK OF____________

NAME	Recording	Photometer	W.P.C.	Test Volts	Racking Lamps	Rack Schedule	Small C.F.	% C.P.	Life	Averages	Omission	Miscellaneous

Fig. 14.—Form used for reporting errors of employees.

construction, life performance, etc., but as to the conditions of bulb blackening during life and any defects which may have been observed.

After the distribution of test results, the blue print from the original data is filed and the lamps are held in stock for fifteen days after a completed report has been made in order that the lamps may be referred to if necessary.

It will be noticed that certain portions of the work, especially inspections, are delegated to individuals who are experienced operators and who have demonstrated their reliability and fitness for the position through years of experience. However, in order to check these as well as all other operators, every error detected is credited to the one detecting it and debited to the

one making it. This induces a spirit of good natured rivalry among all employees. Each operator endeavors to detect as many errors as possible on other employees and to do his work so as to not have detected errors of his own making. The results are reported (fig. 14) weekly to one head and a weekly report rendered. The results based on the errors which an employee detects on others less the ones detected on himself are posted. Furthermore the errors are classified under various headings so as to evince at a glance deficiencies which need to be remedied.

Since some operators, owing to the nature of their work, cannot detect errors, the results do not signify the relative standing of the various operators; but by comparing a series of reports it is possible to tell whether or not an employee is making progress.

In the working out of certain problems of research and investigation, which are more or less outside of the routine work, this obviously can be turned over only to men whose previous training and work have shown their ability to handle propositions of this nature. However, as a check on this class of work the entire test caluculation and summary must be gone over carefully by the associate engineer of the department and his approval is required before the facts are accepted as authoritative. He is at liberty to require any kind of a check which he may think advisable, has access to all parts of the department and all records, and is considered final authority upon questions of accuracy and quality of work.

The fact that a method of checking vital points exists, tends not only to make employees more careful on these points alone but likewise on all other items of their work. The result is more careful and more accurate work throughout the entire organization with the consequent rise in quality of the work done, better service to customers, and at a lower cost to the organization.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. JUNE, 1912. NO. 6

COUNCIL NOTES.

The council held a meeting in the general office of the society June 14.

A report of the society's membership and finances was received from the assistant secretary. The expenses for the first five months of 1912 were given as $4,435.66; the current assets were given as $4,986.12 and the current liabilities as $795.80. According to an estimate of the probable income and outgo for the rest of the present year, a deficit of approximately $1,000 is anticipated.

A report was received from Mr. G. H. Stickney on behalf of the 1912 convention committee. It was understood that the committee would proceed with the convention arrangements. The dates that were decided upon for the convention were September 16 to 19.

The committee on illumination primer presented its final report on the preparation of the primer. The complete primer accompanied the report. In acknowledgment of the excellent work of the committee the council passed the following resolution:

"WHEREAS, the publication of the illumination primer is an important pioneer step of the Illuminating Engineering Society in the dissemination in a popular way of the principles of illumination, and

"WHEREAS, the preparation of the primer has demanded from those in charge of this most important work not only a broad knowledge of illumination but also the exercise of keen judgment in the selection from a vast amount of material available only that most suitable for the purpose, and

"WHEREAS, the successful completion of this task has been accomplished only by the unselfish devotion of the members of the committee to the work; be it

"*Resolved*, That the council express to the members of the

committee appreciation of their untiring labors and extend to them and their co-operators the hearty thanks of the society."

The primer and the report appear in this issue of the TRANSACTIONS. A special edition of the primer will be published, in accordance with the recommendations of the committee, about September 10.

A report was received from the chairman of the committee on new membership. It embodied progress notes from the several section membership committees.

Progress reports were also received from the committee on reciprocal relations with other societies, the advertising committee and the committee on symbols.

The monthly report of the section development committee contained two recommendations:

First: That the council appoint a committee of say five, consisting largely or entirely of Cleveland members, to reconsider the question of establishing a section of this society at Cleveland.

Second: That the council, either as a committee of the whole or acting through its executive committee, consider, and in the event of favorable consideration, instruct the constitution revision committee to formulate changes in the constitution which will permit the appointment of local secretaries to represent the society in a number of the larger cities of the country where no section is at present established. The purpose of this innovation is to promote knowledge concerning the work of the society and to extend its influence wherever possible, by means of arranging for an occasional meeting to be held under the auspices of the society jointly with some local body, and by such other means as may be approved.

The report was accepted and it was understood that both recommendations would be carried out.

Messrs. E. B. Rosa and Walter C. Allen of Washington were appointed official delegates of the society to the Twenty-third International Congress of Hygiene and Demography under the auspices of the United States Government in Washington in September.

The following constitutional revision committee was appointed: Messrs. W. D. Weaver, chairman; C. H. Sharp, vice-chairman; E. P. Hyde, G. H. Stickney, L. B. Eichengreen, R. C. Ware, H. S. Evans and Edward Wray.

Messrs. Henry B. Dates, S. E. Doane and E. P. Hyde were

appointed members of a committee which is to consider the advisability of establishing a section of the society in Cleveland. The appointment of additional members to be named by the president was approved.

A letter from Mr. Arthur Williams, general inspector of the New York Edison Company, in which he commended the society for the work it has done and is doing to the benefit of central stations, was received.

The council expressed an opinion that a change in the society's fiscal year seemed desirable; and that a by-law covering a uniform election procedure for sections should be included in the constitution and by-laws. Both these suggestions were referred to the constitutional revision committee.

The following letter was received from Mr. F. L. Hutchinson, secretary of the American Institute of Electrical Engineers:

"I have the honor of notifying you that Messrs. Edward Pechin Hyde, Van Rensselaer Lansingh, Louis B. Marks and Addams Stratton McAllister, who are members of your society as well as of the American Institute of Electrical Engineers, have been appointed by the president of the Institute to serve as members of the Committee on Organization of the International Electrical Congress to be held at San Francisco in September, 1915. In the published lists of this committee these gentlemen will be accredited to the Illuminating Engineering Society."

Relative to this letter the following resolution was adopted:

"*Resolved*, That the council of the Illuminating Engineering Society cordially approves the action of the president of the American Institute of Electrical Engineers in selecting four members of the society who are also members of the American Institute of Electrical Engineers to serve upon the committee on organization of the 1915 Electrical Congress, and trusts that this representation may further promote the cordial co-operative relations existing between the two bodies."

Following is an excerpt from the report of the committee on financial policy, Mr. L. B. Marks, chairman, in regard to the classification of the society's membership in order to increase the annual revenue of the society. The report was signed by a minority of the committee.

After an extended discussion of the various phases of the situation, it was decided tentatively to recommend to the council that the membership of the society be divided into three classes as follows:

Class A, to pay $10.00 annual dues, and to have all of the present privileges of members.

Class B, to pay $5.00 annual dues, and to have all of the privileges of Class A, except the right to hold elective office in the society-at-large.

Class C (companies or firms), to contribute $25.00 annually, and to be entitled through their accredited representative to all of the privileges of the society except the right to vote and to hold office.

With reference to Class A members, it was thought that if a suitable appeal is made to the members, at least one-fourth to one-third (say about 400) of the present membership would enroll as Class A members, yielding an increase of $2,000.00 in dues.

As Class B members would have all of the privileges of Class A, including the right to vote and hold office in the sections, and excluding only the right to hold elective office in the society-at-large, it was thought that there would be few, if any, defections as a result of this classification.

It was thought that from 50 to 100 companies and firms would respond to the call to contribute $25.00 a year to the cause, even though such contribution did not carry with it the right to vote and to hold office in the society.

The report was tabled for consideration on or about the time of the convention in September. A new committee, the committee on revenue, was appointed to consider the matter of increasing the society's income and to make definite recommendations about that time as to how this might be accomplished. The personnel of this committee is as follows:

W. J. Serrill, chairman; J. T. Maxwell, R. C. Ware, A. S. McAllister, Albert J. Marshall.

The question of including personals in the TRANSACTIONS was laid on the table pending a consideration by the editing and publication committee of a proposal to divide the TRANSACTIONS into two parts, a news section and a section devoted entirely to papers and discussions.

In attendance at the meeting were: Messrs. V. R. Lansingh, president; George S. Barrows, James T. Maxwell, C. J. Russell, W. Cullen Morris, L. B. Marks, Albert J. Marshall, R. C. Ware, W. J. Serrill, and Preston S. Millar, general secretary.

SOCIETY NOTES.

The New England section held a meeting in the auditorium of the Edison Electric Illuminating Co., Boston, June 10. The paper presented for discussion was a symposium on Indirect, Semi-indirect and Direct Lighting, by Messrs. T. H. Rolph, J. G. Henninger and S. G. Hibben. The symposium and the attending discussion appears in this issue of the TRANSACTIONS.

JOINT MEETING OF A. I. E. E. AND I. E. S.

During the annual convention of the American Institute of Electrical Engineers in Boston, June 25 to 28, inclusive, one session was given over to a joint meeting with the Illuminating Engineering Society. The following papers were presented: "Industrial Illumination and the Average Performance of Lighting Systems" by C. E. Clewell; "Relations of Illuminating Engineering to Electrical Engineering" by Dr. Louis Bell; "Demonstrations of Some of the Relations of Color to Illumination Work" by Dr. H. E. Ives; "Problems of interior Illumination" by Mr. Bassett Jones, Jr. The society was well represented by members in attendance. The papers were enthusiastically received and the attending discussions were both interesting and timely.

COMMITTEE ON NOMENCLATURE AND STANDARDS.

The committee on nomenclature and standards invites the membership of the society to co-operate with it in its work by furnishing suggestions as to the terms and quantities which should be standardized and defined, by submitting definitions for the consideration of the committee, and by making any other proposals regarding matters lying within the committee's scope. Communications may be addressed to Dr. A. E. Kennelly, chairman, % Pierce Hall, Harvard University, Cambridge, Mass.; to Dr. C. H. Sharp, secretary of the committee, 80th Street and East End Avenue, New York City; or to the main office of the society, 29 West 39th Street, New York City.

SYMPOSIUM ON INDIRECT, SEMI-INDIRECT AND DIRECT LIGHTING.

PART I. IMPORTANT ENGINEERING CONSIDERATIONS.

BY THOMAS W. ROLPH.

The illumination received from the majority of lighting systems can properly be treated as made up of two parts—the direct and indirect components. The direct component is that portion of the illumination which is obtained from the light-units (the lamps and their equipment) directly, without reflection from ceiling or walls. The indirect component is that portion of the illumination which is produced by light reflected from the ceiling or walls or both before being received on the plane of illumination. Some lighting systems have one component only, *i. e.,* they are totally direct or totally indirect. Obviously, the direct component is more efficiently obtained than the indirect. Until the recent more general introduction of indirect lighting, the physiological value of the indirect component of a system was but vaguely realized and the principal engineering aim in practically all lighting systems was to increase the direct component, thereby increasing the illumination efficiency.

There are, however, certain distinct advantages which a high indirect component of the illumination possesses compared with a high direct component. In an appreciable number of lighting propositions, these advantages will justify the comparatively low efficiency of indirect or semi-indirect lighting. This paper is an attempt to formulate the principal advantages and disadvantages of a high indirect component and to bring out the important factors which should determine the most desirable proportions of the direct and indirect components, when the latter is comparatively high.

ADVANTAGES OF A HIGH INDIRECT COMPONENT.

The advantages of a high indirect component are due to the diffusion of the light comprising the indirect component. Diffusion might be termed multi-directional character of light. In

* A paper read before meetings of the Pittsburg and New England sections of the Illuminating Engineering Society, May 17 and June 10, 1912, respectively.

other words, with diffused light, the illumination at any point is produced by light-rays coming from many different directions rather than from a single direction. It is apparent that the use of a large area like the ceiling for a secondary light-source necessarily results in multi-directional or diffused light. The principal advantages, which are produced by the diffusion of a high indirect component are: low degree of specular reflection from surfaces worked on; absence of deep and sharply defined shadows; low candle-power and low intrinsic brilliancy of light-giving areas.

Specular or Regular Reflection of uni-directional light from glazed or semi-glazed surfaces produces glare when the eye is in such position as to receive the reflected light directly. Examples of this are very common. With direct lighting, a magazine using half-tone paper held in almost any position will give a glare effect from some part of it. One unconsciously holds it in the position which gives the least glare effect. If all surfaces worked on were perfectly diffuse reflectors of light, there would be no glare even with uni-directional light. Almost all surfaces, however, give a certain amount of specular reflection. The action of glare is to cause what has recently received the well-chosen term "depression of visual function."[1] Depression of visual function is produced when any light enters the eye from objects other than those viewed, or when there is too high an illumination on the object viewed. It varies with the candle-power of the extraneous light and with its angle from the line of vision. The action is a decrease in the ability of the retina to perform its normal functions with the result that the eye cannot distinguish details as well. Consequently, to see with the same degree of distinctness, a higher illumination is required. This is well illustrated by data[2] which Mr. J. R. Cravath presented at the last convention of the society. These data have been graphically arranged by Mr. Arthur J. Sweet[3] and are shown in fig. 1. The tests were made in a room 18 feet, 6 inches by 21 feet with a ceiling height of 10 feet. Five systems of lighting

[1] Arthur J. Sweet, "Influence of Illumination Conditions on Eye-Strain," *Elec. Rev.* and *Western Elec.*, March 16, 1912.

[2] J. R. Cravath, "The Effectiveness of Light as Influenced by Systems and Surroundings," TRANS. I. E. S., vol. VI, p. 782, Nov., 1911.

[3] *Loc. cit.*

were used and with each system the illumination was varied by means of a rheostat in the circuit. A subject was placed in the center of the room with a reasonably diffuse paper (*The Saturday Evening Post*) on a flat desk in front of him. The illumination was then raised until the value seemed to the subject ample for reading. Fig. 1 represents averages of the results from a large number of determinations on twelve subjects. It will be seen that as the extent of diffusion from the lighting system increases, the illumination which the subject considered ample, decreases. While this method of test cannot be relied on for highly accurate results, the data obtained are nevertheless fairly conclusive evidence of the value of diffusion in avoiding depression of visual function. Depression of visual function may or

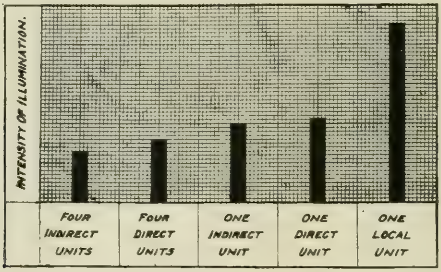


Fig. 1.—Average results in foot-candles considered minimum comfortable for steady reading.

may not be accompanied by decided ocular discomfort. The glare which results from regular reflection of uni-directional light is often great enough to cause decided ocular discomfort as well as depression of visual function.

Absence of Deep and Sharply Defined Shadows is obtained by the multi-directional character of the light composing a high indirect component of the lighting system. It is well to make a distinction here between shadows and shaded areas. Shaded areas may be defined as shadows with indiscernible edges. Shaded areas are always in evidence. Shadows, in the narrow meaning of the word, may be entirely eliminated. A sharp shadow may be very objectionable while a shaded area of the same maximum depth would not be. The value of lack of deep

shadows is self-evident. It varies with different classes of service. In drafting, shadowless illumination is the ideal. In offices, shadows are less objectionable; faint shadows are really desirable to aid in giving perspective to objects. In residences, theatres, etc., some shadow is very desirable. The undesirability of sharp shadows especially in offices, is brought out by fig. 2. This illustrates a phenomenon which physiologists term "induction." The bands are each of the same degree of grayness throughout, but differ from each other in reflecting coefficients. The portion of each band nearest to the next lighter one seems to be darker than the rest of the band. Induction is the phenomenon which makes dark objects look darker when adjacent to

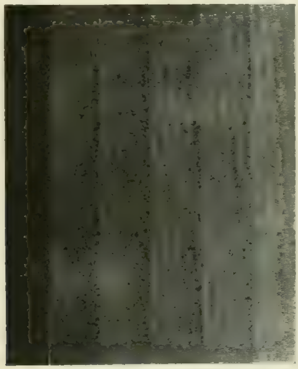


Fig. 2.—Illustration of induction. Each band although uniform appears darker near its right hand edge and vice-versa.

light objects and *vice versa*. The action is often great enough to obscure details, otherwise visible, in a dark object adjacent to a light one. This phenomenon is probably very largely depression of visual function and should therefore follow the same laws. One of these laws is that the nearer an extraneous light is placed to the direct line of vision, the greater is the depression of visual function. The figure illustrates the great sensitiveness of the retina to extraneous light very close to the line of vision, since even the extremely low candle-power obtained from these surfaces is sufficient to make the adjacent surfaces appear darker. It also illustrates the rapid decrease in this effect as the angular distance between the extraneous light

and the object viewed is increased. These points are very suggestive in connection with the desirability of avoiding sharp shadows on working surfaces.

Low Candle-power and Low Intrinsic Brilliancy of Light-giving Areas result from the nature of diffused light. Its multi-directional character precludes the possibility of any appreciable amount coming from a single point or small area. Of course, the direct component may nullify this, but all the light which makes up the indirect component is diffused. Depression of visual function and ocular discomfort are both in evidence to a greater or less degree when a light-giving area of appreciable candle-power or intrinsic brilliancy is in the field of vision or is in a position such as to come into the field of vision even occasionally.

Summing up the advantages of the indirect component of lighting systems one may say that the diffusion or multi-directional character of the light tends to decrease glare due to specular reflection from surfaces worked on; it tends to decrease the depth of shadows and to eliminate their sharp edges; and it tends to protect the eye from brilliant light-giving areas. To what extent these advantages are nullified by a direct component will be discussed further on in this paper when these advantages will be considered in a more quantitative manner.

DISADVANTAGES OF A HIGH INDIRECT COMPONENT.

Having considered the advantages of the indirect component compared with the direct, the disadvantages will be taken up. These are briefly: low efficiency and rapid deterioration due to dirt; light on walls, which may cause depression of visual function; bright ceiling, which may cause undesirable appearance; and lack of perspective, due to lack of shadows.

Of these disadvantages, the first-mentioned is by far the most important. The efficiency of obtaining the indirect component considering the light after it has left the unit may be as low as 10 per cent. of the efficiency in obtaining the direct component (which is, of course, 100 per cent. considering efficiency back to the light-unit only). It may run as high as 50 per cent. in exceptional cases. The disadvantage of low efficiency and rapid deterioration cannot be overcome. Proper design will do much

toward lessening them, but in any lighting system in which the indirect component of the illumination is high, the advantages of that component should be great enough to justify the comparatively high cost of operation and maintenance.

Too much light on the wall will cause depression of visual function. When the indirect component of a system is high, the walls should be dark in color. This disadvantage will then be nullified but this is accompanied by a reduction in illumination efficiency. The net efficiency may not be reduced when the walls are darkened, however, as the increase in visual efficiency may more than make up for the decrease in illumination efficiency.

The brightness of the ceiling increases as the size of the indirect component of the illumination increases. In the case of totally indirect lighting, there is usually a decided contrast in brilliancy between the dark light-unit and the bright ceiling. This is somewhat objectionable from the appearance standpoint. Appearance considerations also render it desirable to avoid, as far as possible, a very bright ceiling or a spotted effect on the ceiling, due to great variation in brightness.

Perspective very largely disappears in shadowless illumination. In a few classes of lighting—drafting, for example—this is desirable. In most classes of lighting it is undesirable. Entire absence of shadows is very rarely obtained, however. Even in totally indirect lighting, the light-giving area of the ceiling is so restricted that some shadow or shaded area is usually in evidence. Still, it is quite possible to have the diffusion too great and the resulting loss in perspective more than the gain in other respects warrants.

It is apparent that by proper design, all the disadvantages of a high indirect component of the illumination can be overcome, to a large degree, except the disadvantage of low efficiency. The latter obviously in no way detracts from the desirable illumination features; it merely makes them more expensive.

FACTORS AFFECTING THE PROPORTIONS OF DIRECT AND INDIRECT COMPONENTS.

The illumination advantages, accompanying the use of a relatively high indirect component of illumination has led to considerable use of lighting systems in which there is no direct

component and more recently to systems in which the direct component is present, although small. It is desirable to determine what proportions of direct and indirect components are best, in order to obtain to their fullest extent and most efficiently the advantages of a high indirect component. Other things being equal, the greater the direct component, the higher the efficiency; yet the direct component may be increased to a value such that the advantages of the indirect component are largely nullified. If that point is reached, the sacrifice in efficiency to obtain a high indirect component is unwarranted. To justify the comparatively low efficiency of a high indirect component, the proportions of direct and indirect light should be such that the advantages of the indirect component will be obtained to the most desirable degree and the disadvantages as little as possible. Below is a restatement of these advantages and disadvantages.

Advantages: Diffusion of light resulting in (a) low degree of specular reflection from surfaces worked on; (b) absence of deep and sharply defined shadows; (c) low candle-power and intrinsic brilliancy of light-giving areas.

Disadvantages: (a) Low efficiency and rapid deterioration due to dirt; (b) too much light on the walls; (c) bright ceiling, which may cause undesirable appearance; (d) lack of perspective, due to lack of shadows.

Of the aforementioned disadvantages, efficiency should be given little weight. The efficiency of direct lighting is abandoned in order to obtain an indirect component of appreciable size. If any lighting proposition warrants this sacrifice, it also warrants neglecting the slight changes in efficiency which a variation in the direct component will make, and justifies the determination of the direct component on the grounds of illumination results only. The question of too much light on the walls may also be neglected here since dark colored walls are to be recommended. Similarly, ceiling brightness is of very minor importance in a consideration of the direct component, but the contrast between bright ceiling and dark bowl points to the desirability of a direct component large enough to prevent this.

The important questions are: To what extent is diffusion or multi-directional light desirable, from the standpoints of (a) extent

of specular reflection allowed by good practise? and, (b) depth and sharpness of shadow allowed by good practise? What brightness of bowl is desirable from the standpoints of eye-protection and contrast? Finally, what percentage of direct component will give these?

Diffusion is the most important consideration. As has been already pointed out, one of the principal reasons for diffusion is the specular reflecting character of surfaces commonly worked on. The surface which may be taken as the extreme is the half-tone paper of magazines. Such surfaces are in common use and likely to continue so for many years to come. A fair criterion of the diffusion desirable is that it shall be such as to allow comfortable reading from half-tone paper in any position. Any uni-directional light will give glare effect in some position with such paper. This criterion will therefore dictate that the brilliancy of the unit should be no greater than the maximum brilliancy of the ceiling, assuming the area of maximum brilliancy is great enough to cause no appreciable specular reflection. Any light emitted by the unit will then be practically of the same intensity as the light coming from a similar nearby area of the ceiling. The two will merge and there will be no glare from regular reflection due to the direct component of the illumination. Great accuracy is not necessary in determining what per cent. direct component will give this degree of brilliancy. Indeed, great accuracy is impossible since ceiling brightness will vary in practise with the color of the ceiling, the distribution from the unit and the distance of the unit below the ceiling; while the brilliancy of the unit will vary with its size, assuming the direct component to be constant. It is profitable, however, to consider an average case. In the illumination tests of Messrs. Sweet and Doane,[4] recently reported to the society, the semi-indirect unit, comprising a prismatic reflector and an art glass envelope, had a brilliancy only slightly lower than the maximum brilliancy of the ceiling when the latter was white. The prismatic reflector was of the focusing type and the brilliancy of the ceiling would therefore be considerably lower with a wider distribution, which

[4] Arthur J. Sweet and L. C. Doane, "The Choice of Reflector: Its Influence upon Illumination Efficiency and Depression of Visual Function;" a paper read before the New York section of the Illuminating Engineering Society, Feb. 8, 1912.

is more generally used and more desirable from the standpoint of obtaining diffused illumination. It is highly probable, therefore, that to obtain no specular reflection on working surfaces, due to direct light, the percentage of direct light should be as low or lower than in the unit referred to. With this unit, the proportions of the illumination received directly and indirectly, with white ceiling and white, medium, and dark walls respectively, was in the tests referred to, 11 per cent. and 89 per cent.; 13 per cent. and 87 per cent.; 14 per cent. and 86 per cent. It seems reasonable to assume therefore, that the elimination of specular reflection from working surfaces will be obtained to the most desirable degree if the direct component of the illumination is no greater than 12 per cent. Obviously, the direct component may drop to any value below 12 per cent. and the results will be as good from the standpoint of eliminating specular reflection.

The question of sharpness of shadow and depth of shadow permissible has almost the same degree of importance as the question of specular reflection. Fig. 2 is ample proof that shadows, even though faint, should not be sharp. Any shadow caused by the direct light from the unit will be fairly sharp, the degree of sharpness depending on the size of the unit. The author has had a number of these induction diagrams made to determine what degree of difference in reflecting coefficients of surfaces would cause a depression of visual function. It was found that when the bands differed by 30 per cent. in reflecting quality, the depression in visual function was appreciable, but when this difference was reduced to 20 per cent., the phenomenon was only barely perceptible. This would indicate that a sharp shadow of 20 per cent. on working surfaces is about the limit of good practise for illumination in which any close visual work is to be performed.

Further data bearing on the degree of shadow permissible were obtained by Messrs. Sweet and Doane, while conducting their illumination tests above referred to. A series of observations was made by a number of engineers familiar with illumination requirements. Observations were made by each engineer while seated at a desk under the lighting systems tested. In each case, he expressed his opinion as to the degree to which

shadows seemed objectionable. An illuminometer was used to measure the density of the shadow. The experimenters concluded that with direct lighting (*i. e.*, shadows with fairly sharp edges) a shadow of 10 per cent. on the work is about the lowest which is noticeable enough to attract the attention of the average worker and hence be annoying in some classes of work. Shadows lower than 10 per cent. may be plainly visible, but ordinarily would not attract attention. Work could be performed in a shadow of 10 per cent. density. The annoyance caused is due to the shadow edge rather than to contrast. The experimenters concluded that a 40 per cent. shadow on the work was the absolute limit permissible by good practise. Here the evil effect of the shadow is due to contrast making the shaded portion appear too dark for a working area. Judging by the diagram illustrating induction with a 30 per cent. difference in shaded area, the depression of visual function near the edge of a 40 per cent. shadow must be considerable. It was found that with totally indirect lighting (*i. e.*, giving shaded areas rather than distinct shadows) a 50 per cent. shaded area was not at all objectionable. The experimenters did not obtain an objectionable shadow or shaded area with indirect lighting. This is not surprising when it is considered that in fig. 2, the depression of visual function extends over only a small portion of each band. It is probable that a very high percentage of depth of shaded area (shadow with indiscernible edge) is not objectionable, unless the actual illumination intensity in the shaded area is lower than the class of service demands.

In order to obtain the best results, from the shadow standpoint, it seems desirable to have no sharp shadows of greater density than 15 per cent., on working surfaces. This is approximately the limiting density at which contrast might produce depression of visual function as in fig. 2. It should be low enough for good results in office work, although for drafting a 10 per cent. shadow limit on working surfaces would probably be better. Other classes of lighting might not require as low a shadow limit for best results. On the whole, however, a 15 per cent. sharp shadow is probably a desirable average high limit for semi-indirect lighting. The low limit should be determined largely by the degree of

shadow necessary to obtain perspective. From the shadow tests, reported above, it is evident that this limit is in the neighborhood of 10 per cent. The most desirable sharp shadow is probably, therefore, from 10 to 15 per cent. This means that the direct component of the illumination should be (from the shadow standpoint) from 10 to 15 per cent. of the total illumination, since the direct light will cast a shadow with fairly sharp edges.

The question of eye-protection demands that the intrinsic brilliancy and the candle-power in the direction of the eye be low. The intrinsic brilliancy of the ceiling in indirect and semi-indirect systems is sometimes none too low for best eye-protection. It therefore seems that a fair criterion for the limiting brilliancy of the unit from the standpoint of best eye-protection is the criterion adopted for elimination of specular reflection, *i. e.*, that the unit have no greater brightness than the ceiling. While this specification cannot be considered as rigid, it is nevertheless approximately what it is desirable to work to. Certainly, if the transmission is increased any considerable amount the unit will cause eye discomfort when viewed. It should be noted that many installations allow the light-units to be placed so high or in such a position that they are rarely looked at. In that case the desirability for low intrinsic brilliancy is not so great. However, if the unit is allowed to be much brighter than the ceiling, it will be quite comparable in brillancy with many direct-lighting units. If such a point is reached, semi-indirect lighting is no longer justifiable from the standpoint of eye-protection from the unit. In other words, the advantage of semi-indirect over direct lighting from this standpoint disappears and the inefficiency of semi-indirect must be justified on other grounds than that of protection to the eyes from the unit. As has been pointed out under a consideration of specular reflection, the unit will have the same degree of brightness as the ceiling under average conditions when the direct component of the illumination is approximately 12 per cent.

CONCLUSIONS REGARDING THE DIRECT COMPONENT.

From the foregoing text, the following conclusions regarding the direct component of the illumination may be deduced: (1) For the best degree of elimination of specular reflection on work-

ing surfaces it should be little greater than 12 per cent. (2) For best shadow values it should be from 10 per cent. to 15 per cent. (3) For best degree of eye-protection it should be little greater than 12 per cent.

These values cannot be taken as exact, since the present state of our knowledge of the subject does not permit of exact determinations. At the present time, however, one may say with reasonable certainty that in order to obtain, to the most desirable degree, the advantages of a high indirect component of the illumination, the direct component should be from 10 per cent. to 15 per cent. of the total illumination. Departure from these values will probably lessen the engineering advantages of this class of lighting. If the direct component of the illumination is decreased below 10 per cent., there is apt to be loss of perspective and, if it goes as low as zero, undesirable appearance factors are likely to be introduced. If the direct component of the illumination is increased beyond 15 per cent., the advantages of the indirect component are apt to be seriously reduced. There is undoubtedly some value, not far beyond 15 per cent., at which the illumination advantages of a high indirect component are so seriously reduced that the comparative inefficiency of this class of lighting is no longer justifiable on engineering grounds. It must then be justified mainly from the esthetic standpoint—a difficult task, considering the variety of attractive direct-lighting units available.

There are, of course, a great number of lighting propositions, for which the diffusion and consequent illumination advantages of a high indirect component are quite unnecessary. Probably, for the great majority of installations the higher cost of indirect or semi-indirect lighting is not warranted on engineering grounds. In a few classes of service—drafting-rooms and picture galleries, for example— the diffusion is, undoubtedly, of sufficient value to warrant the high cost. In any class of lighting, however, a well-designed direct system is preferable, on engineering grounds, to a semi-indirect system in which the direct component is great enough to seriously reduce the illumination advantages of the indirect component.

PART II. COMPARATIVE EFFICIENCIES.
BY J. G. HENNINGER.

Consider these systems of illumination from the standpoint of efficiency alone. Averages taken from a large number of tests show that under favorable conditions an indirect lighting system will average about two lumens per watt on the plane of illumination. Small rooms with light walls and ceilings will sometimes show an efficiency as high as 2.5 lumens per watt, while in large rooms with high ceilings, the efficiency may come down to 1.5 lumens per watt and perhaps less.

An extremely interesting test to determine the relative efficiency of an indirect versus a direct system of lighting has just been completed by the National Electric Lamp Association. The room in which the test was conducted is 19 ft. by 39 ft. 7 in. with a 12 ft. 2 in. ceiling. The walls are light yellow and the ceiling flat white. The lighting was provided in the one case by eight 150-watt X-Ray tungsten units uniformly spaced in two rows of four each; while in the other, eight 150-watt tungsten lamps equipped with prismatic reflectors were used in the same outlets. Conditions were made as nearly uniform as possible so that the results would be comparable. Another interesting feature of the test is that both clear and bowl frosted lamps were used. The effective lumens per watt are not as high as would be expected under the conditions. But this is readily accounted for when it is considered that a large portion of the end wall adjacent to the test space is made up of windows covered with dark green shades. Furthermore, on account of the beam construction of the building the lamps had to be placed closer than they should be to the side walls.

	Direct illumination		Indirect illumination	
	Clear	Bowl frosted	Clear	Bowl frosted
Average intensity of illumination	6.39	5.63	2.77	2.40
Effective lumens per watt	4.00	3.52	1.73	1.51
Relative per cent. based on clear lamp, direct system	100.0	88.0	43.3	37.7

Another test conducted on an indirect lighting unit in a small room afforded some interesting information. The dimensions of the room were as follows: length, 9 ft. 10 in.; width, 8 ft.;

ceiling height, 8 ft. 3 in.; unit at standard position was 12 in. from ceiling.

	Effective lumens per watt
Black walls, white ceiling	1.66
White walls, white ceiling	2.43

Maximum variation reduced from 70 to 47% by white walls.

Illumination measurements taken with the unit at various distances from ceiling gave the following results. The farther from the ceiling, a little more uniform was the illumination. The best hanging height is plainly evident from these data.

	1 foot	1 ft. 6. in.	2 feet	3 feet
Extreme variation above average, per cent	21.5	19.3	22.7	21.4
Extreme variation below average, per cent	22.0	21.1	20.2	17.6
Effective lumens per watt	2.65	2.90	2.69	2.66

A third test was conducted in a barber shop lighted by means

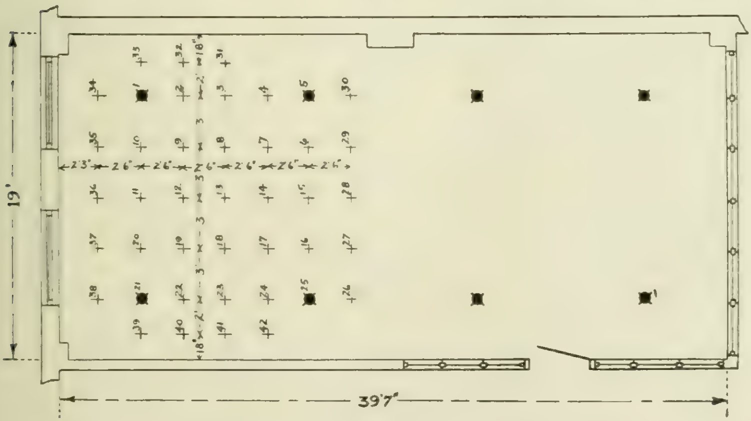


Fig. 1.—Location stations in test of direct versus indirect lighting.

of a semi-indirect system. The shop was 36 ft. by 18 ft. with a 12 ft. 6 in. ceiling. The lighting equipment consisted of three 4-lamp fixtures uniformly spaced along the center of the room. Each fixture was equipped with four 100-watt lamps fitted with inverted translucent glass reflectors. There was a wainscot of white marble about 36 in. high along two sides and across the end of the room, while above this was a line of mirrors reaching to about 7 ft. above the floor. The remainder of the walls and ceiling was tinted a light buff. The test results were as follows:

	Foot-candles
Average intensity of illumination	5.78
Watts per square foot	1.875
Lumens per watt	3.08

Another interesting series of tests was conducted, using prismatic glassware and tungsten lamps. The room was 18 ft. 10 in. by 23 ft. with a beamed ceiling 13 ft. 10 in.—beams 15 in. by 5.5 in. on four-foot centers. The walls were of natural pine finish while the ceiling was painted with "factory white".

The reflection from the walls was not very good while the ceiling was in fair condition.

In the first case the units were hung in their normal positions and illumination measurements taken. Then the units were simply turned upside down and suspended by cords at a distance of 4 ft. from the ceiling which happened to be about the same height at which the units were previously hung. Lastly, the reflectors were surrounded by a cone of bristol-board, the inside of which had been painted a dead black, the idea being to determine exactly what portion of the illumination obtained with the inverted system was due to reflection from the ceiling. The results are tabulated below.

	Effective lumens per watt	Maximum variation per cent.	Relative efficiency per cent. of direct system
Direct	3.04	78	100.0
Semi-direct	1.54	44	50.6
Totally indirect	1.027	55	33.75

Efficiency is unquestionably in favor of semi-indirect illumination as compared with indirect illumination; but how about relative ability to see well, etc.? A drafting room, for instance, can be lighted remarkably well with an indirect system of illumination. There are no bothersome shadows and the workmen are comfortable. On the other hand, I know of a certain drafting room in which a direct lighting system is used. There are two 60-watt bowl frosted tungsten filament lamps fitted with satin-finished prismatic reflectors placed above and in front of each drafting table. The reflectors are good diffusers as well as reflectors. The ceilings are light so that all in all the installation is eminently satisfactory.

In another drafting office four-light semi-indirect lighting fixtures are being used with great success.

In one of the large clerical offices of the National Electric Lamp Association the regular prismatic reflectors have simply been inverted. The results are splendid. Previously, under the direct system, the girls operating slide-rules had complained of their eyes. Many of them had to put on glasses. Under the new system, they are apparently content. Later on a set of satin finished reflectors will be installed. The added diffusion will probably have its effect for the better. The next step will be to turn the system into indirect. The girls are being watched at each step, so that the results bid fair to be very interesting.

The consensus of opinion after Mr. Cravath's paper[1] at Chicago last October had been read and discussed was that there was but slight difference between the intensity required to see well under the two forms of illumination, viz., direct and indirect, provided the installations were equally well made. Diffusion seemed to be the determining factor. It was agreed, however, that there is need of much more comprehensive work along that line.

Still another side presents itself—the esthetic. Many people regretted doing away with the old fireplace on account of its cheerfulness. Hawthorne has lamented this fact in verse. Some people claim that the beauty and comfort of an indirect lighting system is unparalleled. Others claim that indirect lighting—shadowless illumination—is cheerless and cold. It is true that there is a large field in decorative art open to indirect lighting systems. Very charming effects can be and are obtained. The general color tone of the ceiling will largely decide the pevailing color of the resultant illumination—soft warm effect of buff, rose and ivory white decorations, and the cool effect of very light greens, etc. The light units may be covered with various colored glass screens to get the desired colored effect.

On the other hand, there is a large field open before semi-indirect lighting. Myriads of designs in soft alabaster, amber and rose colored glassware are possible. Many wonderful color effects can be produced by them.

It is said that many restaurants and grill room owners use table lamps having soft warm tinted shades for the reason that the resulting illumination is warm in tone and the beauty of the

[1] J. R. Cravath, "The Effectiveness of Light as Influenced by Systems and Surroundings," TRANS. I. E. S., vol. VI, p. 782.

fair sex is heightened by it. There is a feeling of privacy produced by a good table lamp which can be obtained in no other way. Who could ask for more comfortable reading lamps than the old student lamps with their cylindrical wicks and white translucent shades?

The point to be emphasized here is that there is a place for everything. Indirect lighting is not the panacea for every lighting ill. Semi-indirect lighting has its field, and so has the direct. It is true that the fields of each overlap; one merges into the other. Personal opinions vary. One man wants one thing; another something else. However, it is universally agreed that light sources with high intrinsic brilliancy should be kept out of range of vision; streaks are dangerous, and good diffusion is of paramount importance.

Variety is the "spice" of life. Who would like to see everyone's stores, houses, churches, offices, lighted exactly alike? Nobody. Scarcely any of these structures of the same class are alike; architectural requirements vary; decorations vary.

There is an immense field of possibilities open before both systems of illumination. Local conditions and good sound judgment will determine which is most feasible and desirable for each individual case. It will not be an uncommon thing to find both systems used under practically the same conditions with equal satisfaction.

PART III. SEMI-INDIRECT LIGHTING.
BY S. G. HIBBEN.

Indirect lighting may be divided roughly into two classes: opaque units which deliver all of their reflected light directly to the ceiling or upwards to a redirecting diffusing surface; and units which throw some light up and in addition to doing this also transmit more or less light directly through their sides and bottom to the surface or objects to be illuminated. The first class should be known as the strictly indirect system. The second system has of late taken the title semi-indirect. For convenience consider any type of unit that is not opaque but of some translucency as belonging to the semi-indirect type—granting of course that such units have the form of a fixture that depends appreciably upon the upward projected component for its operation. Obviously there may be differing degrees of translucency of the semi-indirect units, but this part of the symposium deals primarily with a general type having a goodly proportion of transmitted light. It touches upon the advisability of a semi-direct lighting system; the comparison between direct and semi-indirect lighting costs; and the artistic side of the subject, briefly. It presents illustrations of several lighting units, and mentions the various effects of the different ratios of transmitted and reflected light flux as these ratios affect illumination results.

The most nearly complete short consideration of semi-indirect lighting can be made by again dividing the subject into three corelated parts, consisting of, (1) the distribution of illumination, (2) the relative costs of lighting, (3) the decorative and esthetic results and possibilities.

Distribution of Illumination.—Indirect lighting in general has been proved to be more uniform than direct lighting, other conditions being equal.

When a room is illuminated by this method, obviously the ceiling becomes one of the main sources of light, and just as out-doors on a cloudy day has lighting with smallest shadow, so does the larger light-giving area of a ceiling surface tend towards uniformity of illumination.

Again, the light rays coming from a source to a ceiling will

strike the ceiling and be returned at wider angles to farther points on the floor. The much used analogy of the stream of water that is directed downward to destroy a limited area of one's garden, or pointed upward to spray a large part of the ground, explains this condition best.

Finally, the ceiling as one light source, and the lamp and shade close to the ceiling as another source, form two sources that average much higher in position above the floor than direct lighting sources, and is another reason for wider distribution and more uniformity.

The curves of fig. 1 show some test results of the distribution

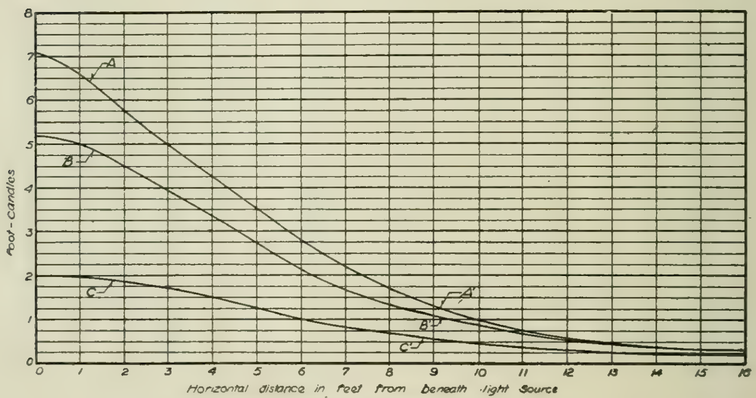


Fig. 1.—Illumination from lighting fixture shown in figure 2.

from one unit. These are curves showing the actual tested foot-candles of illumination upon a surface 30 inches above the floor of a typical office room. The vertical scale gives these values. while the horizontal scale represents linear distance measuring from a point directly beneath the light source. This source was a four-arm fixture supporting four alba glass shades and 60-watt clear bulb lamps held tip upward as shown in fig. 2. The height of the ceiling of this room was 10 feet and the interior was painted a light yellow. The shades were hung 21 inches from the ceiling to the rim (in the inverted position). One fixture only was burning.

Curve A-A' of fig. 1 shows the illumination from the four down-

ward pointing shades, or represents the result obtained from light directly reflected from the shades plus the light that has passed upward through the shades and has been returned by reflection from the ceiling. This would be the curve of ordinary direct lighting. Now if the shades and lamps are inverted, meanwhile keeping the centers of the lamp filaments the same distance from the ceiling, the curve B-B′ of semi-indirect lighting is obtained. Finally, if opaque dead black paper cones are placed

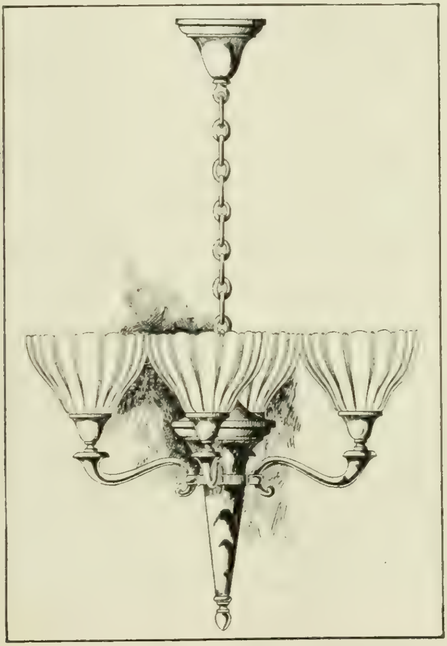


Fig. 2.—A four-lamp semi-indirect lighting fixture.

beneath each inverted shade to cut off all light that may be transmitted downward through the shades, the results shown by curve C-C′ from light coming only from the ceiling are obtained.

The difference between curves B-B′ and C-C′ is due to the transmitted light through the shades. This difference, considering the proportions of transmitted and reflected light from the units standing alone, is apparently great; but its magnitude is exaggerated by these curves, since the curve of indirect light only

(C-C′) is from the upward reflected light after it has suffered a loss from ceiling absorption that may easily amount to from 35 to 55 per cent. The actual proportion of transmitted downward light from the inverted shades to upward reflected light from the shades (calculated from the polar distribution curves) is as 1 to 2.

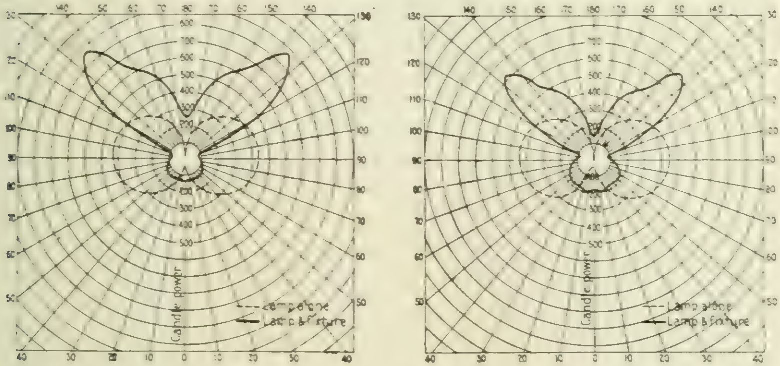
If another case of the effects of transmitted and reflected light, from a fixture as shown in fig. 3 (consisting of a square metal

Fig. 3.—Semi-indirect lighting fixture with mirror-lined metal box.

mirror-lined box supporting a 14 inch glass hemisphere) were considered it would be found that with the use of two different glass hemispheres the polar distributions are as shown by the curves of figs. 4 and 5. The denser and highly polished opal glass directly transmits much less light, and reflects more than the light opal glass. The maximum intensities towards the ceiling are at the same angles in either case. The results shown by the corresponding illumination curves of fig. 6 are what might be expected, viz., with the use of the glass of greater opacity

there is less illumination beneath, and more at a distance between three and eleven feet.

The ratio of downward to upward light, 1 to 2, mentioned above seems to be an excellent proportion for usual service, al-



Figs. 4 and 5.—Light distribution curves from fixture shown in figure 3 with different glass hemispheres.

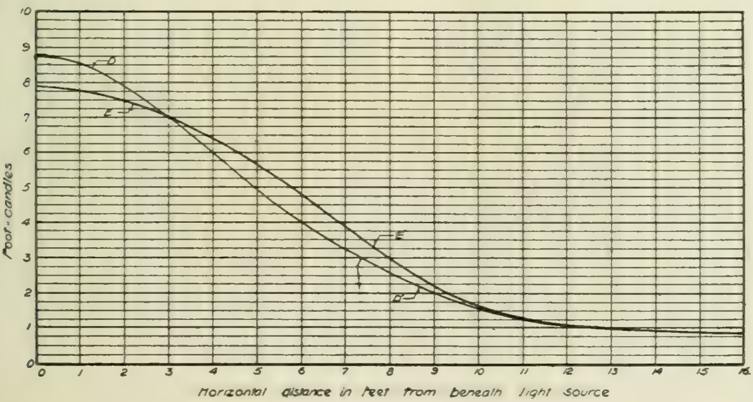


Fig. 6.—Illumination from fixture shown in figure 3.

though there are places where a larger per cent. of transmitted light is advisable, just as there are many places where completely opaque reflectors are advisable. The conditions favoring the first case are units hung high, with a dark ceiling and also high energy costs. The conditions favoring the second case would be under about the reverse circumstances.

Here are the horns of the dilemma: as less light is transmitted, the system becomes more expensive, and more and more dependent upon the ceiling color and cleanliness. On the other hand, as more light is transmitted, the effect draws too far away from the diffused lighting and becomes more like direct lighting, with a chance for higher intrinsic brilliancy of the unit and a possible glare effect. Service conditions must largely govern the point of balance.

One more phase of semi-indirect lighting not shown by the curves is that of light upon vertical surfaces, or striking in sideways to the illuminated object. This is the consideration that effects the draftsman, the type-setter, the detailing clerk and the seamstress. The first half of table I shows what these values are, under conditions identical with those in which curve B-B′ of fig. I was obtained. The second half of this table gives similar data in connection with the installation of the six units referred to in the next topic. The conclusion is that these are high values, and as such explain why nearly all recent drafting room installations are of this particular character.

TABLE I.—TABLE OF FOOT-CANDLES.
Semi-Indirect Lighting Units.

A.

4—Inverted diffusing shades.
4—60-watt clear tungsten lamps.
1—4-arm fixture burning.

Station	Horizontal illumination	Vertical illumination	Direction
2 ft. Dist	4.4	0.38	North
	—	0.45	South
	—	1.24	East (toward fixture)
	—	0.19	West
16 ft.	0.3	0.097	North
	—	0.091	South
	—	0.092	East (toward fixture)
	—	—	West

B.

6—Single semi-indirect units.
6—150-watt clear tungsten lamps.
6—Fixtures burning in a room 20 ft. by 39 ft.

Station	Horizontal illumination	Vertical illumination	Direction
Center of room	3.85	1.44	East
	—	1.47	West
	—	1.85	North
	—	2.03	South

The Relative Costs of Lighting: The second consideration is, how much more does it cost to illuminate an office by the semi-indirect system? There are two answers: one is the answer to the question of costs for equal foot-candles; the other to the question of costs for equal ability to see.

To arrive at an answer to the first question the curves of fig. 1 may be considered. Curve A-A′ represents direct lighting, and curve B-B′ represents semi-indirect lighting. These curves afford a comparison of the lighting results from a single fixture from which it is possible to get a rough working estimate. If this fixture of 4 inverted shades be assumed to illuminate a circle 32 ft. in diameter, the effective lumens (or the area in square feet lighted, multiplied by the average foot-candles over that area) in each case may be calculated. As a summation method of doing this, the writer has taken a series of concentric rings, each 2 ft. wide, and has computed the area of each ring. Then the average foot-candles in each ring or band multiplied by the area of the ring gives the lumens for that ring, and the total for all rings will be the total lumens of the circular area illuminated.

By this means the direct lighting system, heretofore considered as typical, furnishes 1084.3 lumens. The semi-indirect system gives 886 lumens, or 18.3 per cent. less effective light. Hence if the room to undergo a change in system, has been and will remain a medium yellow color then the light flux, or the watts consumed, or the cost of operation, must be increased in accordance with the above proportion. In short, the semi-indirect system would require 22.4 per cent. higher wattage, if it were required to have equal foot-candles in both cases. If the room and especially the ceiling be of a lighter color, the extra cost for energy will be less; if darker, more. Also if the shades transmit less light, the increase will be greater; but these figures are illustrative of this type of unit.

As a check upon this figure, it is of interest to note results of a test made upon an installation of six units, similar to the one of fig. 7. The office room to be lighted measured about 38 by 20 ft. with a 10 ft. cream colored ceiling, and light yellow walls. Six 150-watt lamps were used, spaced approximately at centers of equal rectangles. The distance of the rims of the shades from

the ceiling was 15 in. Six floor stations were respectively located as follows: directly beneath one of the middle units—of one of the two rows of three units each—directly between the two center units; between the middle and end unit of one row; between four adjacent units; at the wall opposite the middle unit of one row, and at the wall opposite the point between a middle and an end unit; in short, such locations as to arrive at the values of a general average of foot-candles of the whole room. The results are given in table II.

The foot-candle efficiency is 0.28 watt per lumen. Using the above factor of 18.3 per cent. as the decrease of illumination of

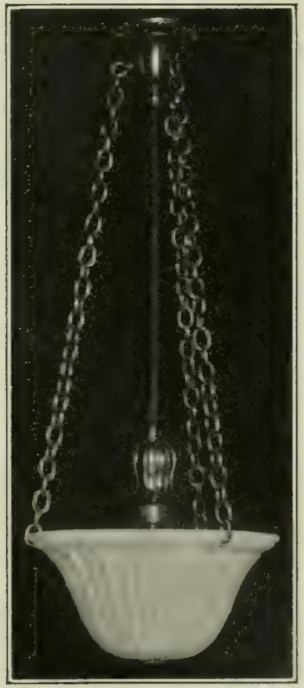


Fig. 7.—Semi-indirect lighting fixture with 150-watt tungsten lamp.

semi-indirect over direct lighting, an efficiency of about 0.23 watt per lumen for direct lighting in this typical room would be obtained, or a close agreement with the generally accepted results

from previous tests of other investigators. This figure of efficiency for semi-indirect lighting is surprisingly good, and may always be applied with a factor of safety, especially since deterioration from deposits of dust is liable to be high.

But this consideration is to be modified for the final answer as

TABLE II.—TESTS OF SEMI-INDIRECT LIGHTING UNITS.

Readings of horizontal foot-candles on a 30-inch working plane.

Tungsten 150-watt clear lamps.
Light opal bowls.
Distance: rim to ceiling, 15 inches.
Color of walls and ceiling: cream

Station	Foot-candles
A	4.89
B	3.85
C	3.22
D	4.25
E	5.39
F	3.22
Average of stations	4.137

Total area illuminated	776.0 sq. ft.
Total energy consumption	900 watts
Approximate watts per sq. ft	1.16
Watts per useful lumen	0.28

to costs. Although under the conditions described, for equal foot-candles and the semi-indirect system requires 22.4 per cent. higher wattage, the question is not one of equal foot-candles but of equal visual efficiency. Under the semi-indirect system there

Fig. 8a.—Contraction of pupil of eye after one minute exposure to a 60-watt lamp four feet away.

Fig. 8b.—Expansion of pupil of eye after three minutes in darkness.

is greater ease of vision. On account of the low intrinsic brilliancy of the light source there is a pupillary expansion of the

eye (fig. 8) allowing more light to reach the retina. Then there are to be considered the results of Fechner's law, if the change in illumination is considerable, which stated briefly is that a decrease in intensity does not mean a proportional correspondingly large decrease in visual acuity; nor the converse. Were this not so, one who in daylight comfortably uses 30 foot-candles of illumination would be greatly embarrassed in attempting to see by moonlight, with 0.03 foot-candles. Third, the more pleasant

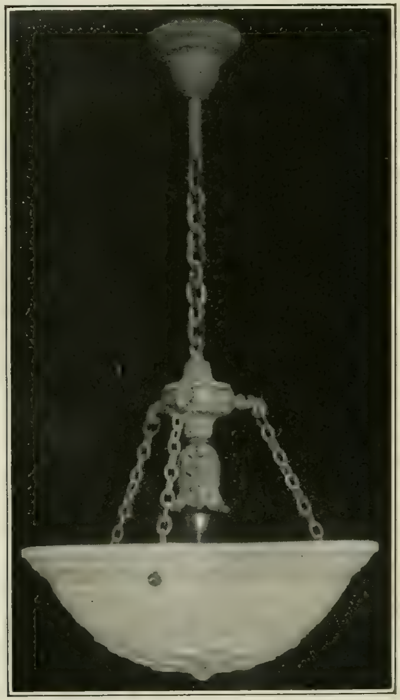


Fig. 9.—Semi-indirect lighting fixture with a 400-watt tungsten lamp.

appearance of the unit and the personal gratification of the senses places the observer's state of nerves and feelings at a place where the sight recording apparatus—quite nervously sympathetic—operates at its best. It is not an exaggeration to claim that in many cases the increased sensitiveness quite often counterbalances the decrease of foot-candles.

Decorative Possibilities: There are often modifying conditions governing the type of lighting unit selected for the various cases, that are widely separated from pure foot-candle efficiency. The physiological effects forms one of these considerations, and closely linked with it is the consideration of decorative possibilities.

As to the units themselves, the accompanying illustrations will serve to give ideas of some few types. Figs. 9 to 11 inclusive,

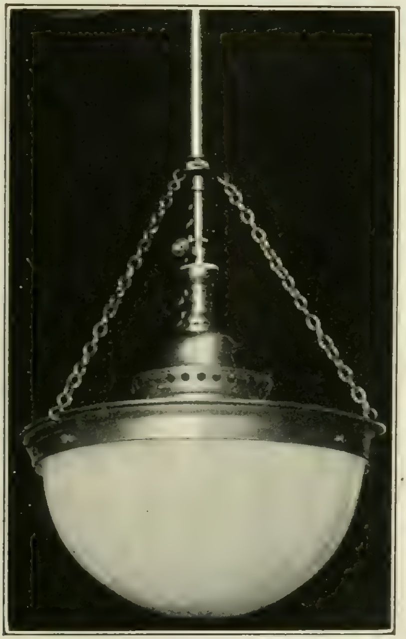


Fig. 10.—Semi-indirect lighting fixture equipped with inverted gas burner.

show both commercial and ornate units, of semi-indirect characteristics, and are typical of the developments so far in this direction.

An idea has long been prevalent that gas, as an illuminant, was of narrow application, and objectionable because of the inartistic forms of fixtures, burners and accessories. But there seems to be no reason why semi-indirect lighting with gas should not have a

prosperous future. Fixtures are in service that consist of translucent glass bowls containing upright mantle burners. Fig. 10 shows a very commercial yet very simple and serviceable semi-indirect fixture using an inverted burner. Beautiful designs in glassware are brought out exceptionally well by these light sources. Any inartistic burner, parts, pilot-flames, etc., are concealed and better disposition may be made of the heat. There

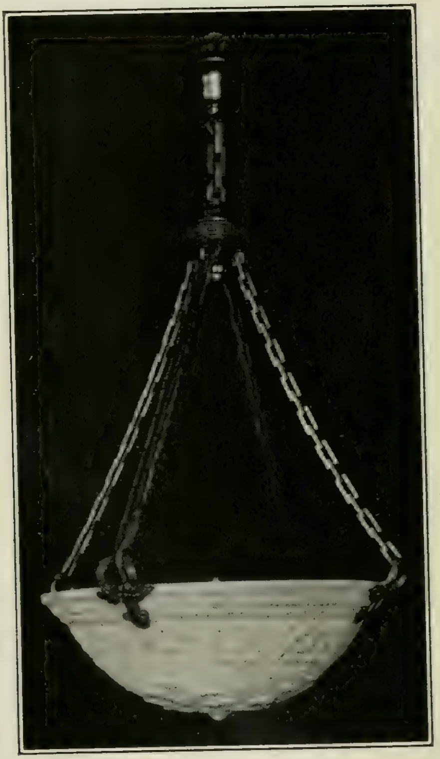


Fig. 11.—Semi-indirect lighting fixture with four 100-watt tungsten lamps.

are on the whole a number of reasons for combining this type of lighting system and this form of illuminant.

Surroundings should be considered in conjunction with the style of the fixtures. With direct or semi-indirect lighting, the prominence of relief designs of a heavily elaborated ceiling can be intensified by laterally thrown shadows. Decorations of ceilings

and walls can be made to appear to their best advantage. The light transmitted through a large glass bowl can be made to blend the unit into the ceiling, colored glass may be used to a striking effect, and on the whole the lighting system can become more nearly a part of the original architectural considerations.

Not everywhere, but in many places there is a field for semi-indirect lighting, and it is hoped that considerations such as these that have been briefly outlined will aid in broadening this field.

Discussion.

Dr. H. E. Ives: I think that papers of this sort, which undertake an analysis of lighting conditions, endeavoring to pick out how much of the light should be direct, how much indirect, and what should be the relative brightness of the light sources and the objects illuminated, are exactly the things we want in illuminating engineering. We need that knowledge before good effects can be produced. We certainly know that deplorable effects can be produced if we misuse the instruments at hand. After we know these facts about the relations between intrinsic brilliancy, diffusion, and direction, I think we shall be within sight of the final thing in lighting.

There is one matter in connection with direct, indirect and semi-indirect lighting which I do not find treated quite as fully as I think it might be in investigations which have been carried on, and that is the matter of *direction.* Some of you may remember that Mr. Luckiesh and I had a paper at the 1911 convention of the society on "The Distribution of Luminosity in Nature." Two rather striking results were set forth. One was that in the ordinary landscape the brightest part is directly in front of the observer; that is, on the horizon line, and that the sky brightness gradually decreases away from that point.

As I sat here this evening I felt there was something lacking in the manner of lighting in spite of the undoubted merit and beauty of these semi-indirect units, and I thought it might be attributed to the fact that the brightest areas in the field of vision are high up on the walls, and for many of the audience are actually the high light sources themselves. Is it not possible that there is a constant straining of the eye upward towards these

bright areas which correspond in brightness to the point which in Nature is on the level of the eyes? That may seem a little far-fetched, yet there is something lacking in an installation of this sort with the light overhead. No matter how attractive the lighting may be when we come in, it doesn't satisfy one after awhile. I would like to have a room lighted in a manner indicating a deliberate attempt to attain natural day light distribution. It might be a total failure, but it seems to me that it is an experiment worthy of your investigation.

The second interesting result of the investigation above referred to was in connection with the *direction* of illumination. Consider now this question of the direction from which the light falls. Investigation shows that the landscapes in Nature are not uniformly pleasing. When the sun is directly overhead and the light is coming straight down almost any landscape is extremely unpleasant. But if the sun is low in the sky so as to make long shadows, the same landscape becomes pleasing. Now consider this room in the daytime. We have windows to one side of large area, say five feet by seven, of comparatively low intrinsic brilliancy and yet of large total candle-power. The light is coming from the side. At night we turn on our lights overhead. There is a vast change in the direction of the light. I would like to see somebody try the experiment of taking these semi-indirect fixtures down and hanging them alongside the windows. Probably they would have to be made considerably larger for the same candle-power in order to decrease their intrinsic brilliancy. I don't know what the result would be, but I would like to see it done.

In conclusion I want to say one more general word. I think we all concur as illuminating engineers to the fact that people should be better educated in what is good and what is bad in lighting. Because of his large influence in deciding on lighting installations, the architect has been the man of all others who ought to be interested in acquiring this education. As Mr. Bassett Jones showed in his recent paper in New York, the whole design of a building may be thrown away by having the direction of light altered from that for which the design was made. Now it seems to me that the old saying that we hear so often, that the

architect plans the building and then turns the lighting over to the office boy, is all too true. The architect too often considers the lighting as a necessary evil to be added after the plan is complete. A few days ago I picked up a copy of *The Studio* and saw there this news item: "In the New York public library there has been introduced an innovation in the lighting." On reading the article I found that the innovation consisted of drawn bronze fixtures in period designs. Now, all of you who have been in that library know that the lighting system consists of drawn bronze fixtures.

One thing the designers of a building should understand is that light and light sources can be made an integral part of the design. I think that anyone who looks at the new indirect and semi-indirect fixtures and sees the great number which are made, which are in themselves things of beauty as light sources, will realize that the illuminating engineer has in them made an argument to the architect for light as an indispensable part of the design for his building. Such a striking appeal to the architects highly developed love of beauty and harmony does what a great deal of lecturing on distribution curves and efficiency data would not accomplish.

Mr. P. S. Millar: This discussion revolves around three fundamentals. The first is the presence of light sources, or other bright objects within the field of vision. The second is diffusion of light. And the third is efficiency.

With regard to the question of light sources within the field of vision, as we all know, there are three ways of overcoming the difficulties: one is to remove the light sources from view, the second is to conceal the sources, and the third is a compromise between the first two. In indirect lighting, the sources are concealed and there is substituted the ceiling—a source of lower specific intensity, but of considerable power. I think there is some objection to a ceiling which is bright locally which has not been emphasized in these papers; in fact, so far as I am aware, we don't know to-day just what relation exists between total flux from a light source and its specific intensity in determining the deleterious effect which it exercises on our ability to see.

I am impressed with the thought that great advances have been

made in the last few years in mitigating the evils of exposed light sources. Compare the kind of glassware which is produced to-day with that monstrosity manufactured a few years ago, consisting of a cluster of sockets, each socket equipped with a lamp and a reflector pointing in various directions around the room in a manner sure to get one no matter from which direction he looked at it. That was an undesirable fixture which the manufacturer would not produce to-day. The change illustrates a big advance in illuminating engineering.

Diffusion of light is a subject which has received attention more recently, the importance of which is only beginning to receive general recognition. Diffusion may be advantageous or disadvantageous depending on the purpose which the illumination is to serve. In a drafting room a high degree of diffusion is essential. In a library it is usually undesirable, insofar as diffusion is taken to mean multi-direction of light producing more or less uniform illumination throughout the room. Diffusion, in the sense of concealing and rendering harmless excessively bright sources, is almost always desirable. The degree of diffusion best for a particular installation is, like most other phases of our complex art, a problem peculiar to that particular installation.

As brought out in the papers, one value of diffussion is to reduce the effect which we call "glare" from calendered paper and polished surfaces. Such effect is due in varying proportions to (a) unidirectional character of light, usually combined with exposed or improperly shielded light sources, and (b) to specular quality of light reflection from surface. At the present time a number of investigators are studying means of reducing glare from reflecting surfaces by securing light of multi-directional character, as employing diffusing globes or employing the ceiling as a reflecting medium, but this society and its membership are doing little or nothing in the way of promoting the use of mat surface paper which would be less liable to specular reflection and therefore less liable to unpleasant glare, even with improperly diffused lighting.

In nature we are accustomed to an exposed light source, often within the field of view, and to light which is more or less unidirectional in character, but we are not accustomed to illumi-

nated surfaces which reflect specularly. While not absent, such surfaces are rare in landscapes, yet in our artificial lighting, we are directing most of our efforts toward removing the light sources from the field of view and rendering them diffusive in character, while that rather unnatural element, the glossy surface which reflects specularly, is receiving but little of our attention. It would be unfortunate if this statement were interpreted as advocating any reduction in the vigor of our campaign against exposed light sources; it is rather in the nature of a suggestion that we, as illuminating engineers, ought to expand our efforts with a view to doing what may be done in the way of promoting the use of mat surface paper where feasible.

The question of efficiency has been discussed by Mr. Henninger, who practically limited his paper to that subject. His tests tend to confirm the impression that I think most of us have held regarding the efficiency of indirect lighting.

When one studies the two components, (a) the direct light from the fixture and (b) the indirect light from the ceiling as Mr. Rolph has done, he enters a realm where generalization is dangerous. The principal danger is well illustrated in the papers we have before us to-night. Mr. Rolph concludes in his paper that the direct component in flux on the plane of utilization should be about 12 per cent. of the total, leaving 88 per cent. for the light which is to come from the ceiling. Mr. Rolph's conclusion is, I fancy, the result of a laboratory investigation. Mr. Hibben attacks the problem from the standpoint of experience in lighting practise, and concludes that a desirable ratio of light thrown downward to light thrown upward is one to two. If we assume that 50 per cent of that thrown upward comes down to the working plane, that means Mr. Hibben's recommendations would be about 50 per cent. direct and 50 per cent. indirect flux. We have then

Pronouncement of	Ratio direct to indirect
Mr. Rolph	$\frac{12}{88} = 14$ per cent.
Mr. Hibben	$\frac{50}{50} = 100$ per cent.

On the seventh page of the symposium Mr. Rolph makes this

statement: "The question of too much light on the walls may also be included here, since dark colored walls are to be recommended." In my opinion such statements are liable to react unfavorably upon the profession of illuminating engineering. Quite aside from the question of its correctness (I fancy that the members of this society would be far from unanimous in rendering a verdict on this point) I feel that the illuminating engineer may, in an installation where it is desirable, exercise his influence to secure a dark finish for the walls, or failing in that, may restrict the light flux impinging upon the walls. If he feels that it is safe to generalize, and is inclined to make a broad statement of this kind, it seems to me that he can, without impropriety apply such a statement to restriction of the specific brightness of walls or even to restriction of the light which falls upon the walls: and since he is dealing with his own specialty, he is not likely to incur criticism on the part of specialists in other fields of activity. When, however, he leaves his own specialty and goes into the realm of decoration, and as an illuminating engineer states unequivocally that dark walls are to be recommended he makes a pronouncement which applies to the entire sphere of decoration and bases his assertion only upon the illumination factor, which is one of a number of factors which the decorator must consider.

I want to say one thing about indirect lighting. One of the big advantages of a new ism is that it generally draws attention to undesirable features of existing isms. Homeopathy, whether or not it is a superior and scientific practise in medicine, has certainly been of great advantage to humanity in teaching allopathy the difficulty involved in the employment of powerful drugs in large doses. Now if indirect lighting were never to go any further than it has to-day, it has been of very great importance in teaching us the value of diffusion in direct lighting. And that is one of the biggest things we have learned in recent years, and I think is very largely due to the commercial exploitation of indirect lighting systems.

Mr. M. Luckiesh: Inasmuch as Mr. Rolph has not expressed himself very fully on reflection from paper, and as his paper takes up that phase of the subject to some extent, a few remarks on the glare from paper might not be amiss. Mr. Rolph has laid

much emphasis, and rightly so, on the importance of glare from paper in determining the character of the lighting-unit to be used in a certain installation.

We are able to read printed matter because of the contrast between the dark letters and the bright background. Any condition which greatly diminishes this contrast should be eliminated. However the use of tinted papers is not condemned. It may be that, although they slightly diminish the contrast they are beneficial; that is, the decrease in the ability to read due to the decrease in contrast may be offset by the possible beneficial effect due to the decrease in the total light flux entering the eye.

The reflection from papers in a combination of diffuse and specular reflection. If one has difficulty in picturing this to himself he can construct a model by placing a sheet of plain glass over a piece of white blotting paper on which some characters are printed. The glass reflects regularly while the blotting paper reflects diffusely. An example will further illustrate how regular reflection from paper obliterates contrast. Assume a perfectly matt surface with black letters upon it illumination to a degree which produces relative brightness of 100 units and one unit for the papers and letters respectively. The contrast ratio in this case is $\frac{1}{100}$. Now assume a white surface which is not matt, but the contrast ratio due to diffusely reflected light is again $\frac{1}{100}$. With the paper in a certain position light will be regularly reflected from both the paper and letters. Very often the letters, owing to their smoothness caused by the pressure of the type, will regularly reflect much more light than the background. Assume a brightness due to this cause of 199 and 100 units for letters and paper respectively. This brightness is superposed on the brightness due to diffuse reflection and the contrast ratio is $\frac{1 + 199}{100 + 100} = 1$, *i. e.*, there is no contrast and no amount of light will make it possible to read.

The type and height of the unit influence to a great extent the amount of glare from paper. The brightness due to regular reflection depends upon the intrinsic brilliancy of the lighting unit

and is constant regardless of distance. The brightness due to diffuse reflection however, varies inversely as the square of the distance from the unit. Other things being constant, glare from paper increases with the distance from the unit. This can be verified by holding a glazed paper close to the unit. There is much less glare. I feel that I should take up no more time here on this subject as I treated it in full in the *Electrical Review and Western Electrician,* June 1, 1912.

The remarks of Dr. Ives and some of the other gentlemen in regard to the direction of this brightest part also have bearing on Mr. Rolph's remark on page two. He has mentioned a number of times that one of the disadvantages of certain systems is too much light on the walls. As a matter of fact, in a room that has moderately light-colored walls, actual measurement will show that the brightest spot in daylight is practically on the horizontal, and I don't think there is any evidence that we suffer very much for such distribution of light.

Mr. J. L. Minnick: I have had considerable to do in the changing of the lighting of quiet a number of buildings during the past year or so, in which all of the lighting is, or was, direct, most of which was produced by the use of carbon lamps. In the study of these conditions it was found that there is a pretty well defined field for the use of every class of lighting, whether it be the use of carbon, metallized, tantalum, or tungsten filament incandescent lamps; or arc, mercury-vapor, gas, or oil lamps, or even tallow candles; and to any one who goes into this subject to any extent, the conditions will gradually work around so as to give very sharply defined lines limiting the field of each type of lighting. Experience has taught me that a semi-indirect lighting system can be used to great advantage in drafting and accounting rooms. In some accounting rooms indelible pencils are used to a very large extent and semi-indirect lighting is the only scheme of lighting tried so far that eliminates the glare from the indelible pencil mark. In drafting room work the absence of shadows is very desirable. Further, I have found in practise in making the change from open lighting, (by this I mean carbon lamps shielded by the ordinary glass or mental reflector) to semi-indirect lighting fixtures equipped with tungsten lamps, one

can save ordinarily from 15 to 20 per cent. in the consumption of energy and will get very much better conditions on the working plane, although there will probably be no higher intensity of light.

There is one other point I desire to bring out and I do not believe it has been touched upon this evening. From experience with the use of indirect and semi-indirect lighting fixtures, I am very much inclined to believe that men can work with greater ease under lower intensity of illumination with semi-indirect lighting than they can with lamps within the scope of vision although the lamps may be partially concealed by the use of reflectors. So much for my discussion concerning the paper.

I wish to take issue with Mr. Millar concerning his remarks relative to the duty of illuminating engineers to stick closely to illumination. My past experience has thrown me in rather close touch with architects and I have found almost invariably that illumination has, to a great extent, been sacrificed for artistic effect and I believe this condition will continue to exist for some time. I believe one of the best things our society can do is to get out as much general information on this subject of illumination as it possibly can. By this I mean a general campaign to educate architects and the users of light, up to the point of making them realize that illumination really amounts to something. As Dr. Iives has said, it is very frequently said of architects that when it comes to laying out the lighting they turn it over to the office boy. Now I am not just sure that such work is turned over to the office boy but I do know that frequently those who lay out the lighting give the problem about as much thought as the office boy would. I recall one installation in which great, large fixtures were designed, made of solid bronze and costing in the neighborhood of $6,000.00 to $7,000.00 each. When the fixtures were installed the lamps could not be screwed into the sockets by reason of lack of space. While this may not be characteristic of all installations, it can be said that a very large percentage do follow this same general idea.

I would like to give Dr. Ives a little better illustration of the designs used in some of our public buildings. I mention particularly the fixtures in the state capitol at Harrisburg. These fix-

tures were so designed that it is possible to make use of only a small portion of the light produced. There are, I think, six ceiling fixtures weighing about 2,000 pounds each. The lamps are in the interior of the fixtures and the openings for the transmission of light are so small that but little light is transmitted. In order to secure sufficient light it was found necessary, after the room was thrown open for use, to run wood moulding around the room at the border line using porcelain wall sockets and bare lamps set horizontally and spaced closely together.

Dr. Ives has also brought up the question of lighting a room by producing the conditions of daylight. There is such a room in existence, the only one I know of, however; it is in the north side of the Masonic Temple at Broad and Filbert Streets, Philadelphia, on either the second or third floor. I think the lighting of this room gives even a more pleasing effect than does daylight illumination. There is a little more color to it and I think it is this that gives the more pleasing effect. The illumination was evidently carefully planned. There are windows along one side of the room, but there are no windows at the ends. In the inner wall, pockets of the size, shape, and similar location, of the windows have been installed. They are about 18 inches deep and the enclosing glass is of the same size and shape as that used in the windows. It is, however, either opal glass or plain glass with a frosted or etched surface. Specially designed reflectors and incandescent lamps are used, the lamps being very closely spaced.

Mr. C. E. Clewell: Under the subject, "Engineering Considerations" in this symposium the author refers to the disadvantages of a high indirect component. These disadvantages have been enumerated as follows:

(1) Low efficiency; (2) Rapid deterioration due to dirt; (3) Bright walls with glare; (4) Bright ceiling with poor appearance; (5) Lack of perspective.

Low Efficiency.—There is a marked tendency to view the whole problem of efficiency in an unwise manner as regards illumination, particularly from the commercial standpoint. The question of efficiency, although given first place in the foregoing list of disadvantages, is by no means an all-important one.

Illumination has so vital a bearing on the work and living

conditions of the average person that its effectiveness in aiding the workmen in their duties is the prime consideration.

If there are any distinct illumination advantages in one system over another, these advantages are apt to be productive of secondary helpful results in the improved work made possible thereby. Thus, the difference in the efficiency of the two systems may become entirely negligible. The points of excellence between two methods of lighting in their relation to those influenced by the effects, should be given preference in the consideration of various systems.

Illumination efficiency then becomes a matter of the gross results produced. One scheme may consume more watts per lumen, but this may be greatly offset by the saving of a very small amount of time to the workmen using the light. The effectiveness of any method of lighting should, therefore, be given first place in preference to isolated efficiency values.

From these viewpoints, the gross efficiency of a lighting system with a high indirect component may often be far superior to a system of the opposite class.

Dirt Deterioration.—The system possessing a high indirect component is referred to in the first part of the symposium as subject to rapid deterioration with dirt accumulations. Tests do not bear out this statement as a generality. For example, two systems, one with a high direct component, namely reflectors pointed vertically downward, and the other with a high indirect component, namely reflectors inverted, have been the subject of investigation for a number of months. It has been found under substantially similar conditions that the deterioration due to dirt has been essentially the same in the two systems over a period of several months.

Here again the attitude is seemingly at an unfortunate angle. The fact that a system requires fairly frequent attention seems to the average person a great disadvantage. All lighting systems, however, should receive fairly frequent attention for cleaning and renewal purposes. The item of prime importance is, therefore, to give each system the required attention, and the difference in the cost of maintenance between the direct and the semi-indirect system, if there be a difference, is apt to be so small as

to be well neglected as far as giving it a place of importance above illumination advantages.

Bright Walls.—This feature may easily be obviated by tinting the walls away from a pure white, but the objection here raised is practically non-essential if the semi-indirect system is properly designed.

Bright Ceiling.—A suitable spacing of inverted lighting units with the proper relation between the spacing and the distance between lamps and ceiling, will cause the brightness of the ceiling to be made up of relatively small sections, thus relieving the effect which may result if the ceiling is uniformly illuminated.

Lack of Perspective.—The resulting illumination produced by the so-called semi-indirect system is such that there is a sufficiency of shadow for every ordinary purpose. So great in fact is this shadow effect, although hardly noticeable under ordinary circumstances, that in the writer's observation type forms in printing house composing rooms have been easily read under a semi-indirect system. The shadows are therefore sufficient to give the necessary relief to the letters in such type forms.

Reflectors for the Semi-Indirect System.—A fair and positively impartial opinion of the most suitable reflectors for use in an inverted position leads to the choice of an opalescent glass. The writer does not agree with one of the authors that the prismatic glass reflector furnishes illumination which may be called as excellent as in the case of other reflectors which may be used for this purpose. Tests under extended service and with very large semi-indirect systems have been the basis for this conclusion.

Concluding Items.—The foregoing notes have been presented not for the purpose of proving or disproving the merits of the various systems under discussion, but rather to give balance to the various items set forth in the papers. It is sincerely hoped that when questions of this nature are under discussion that the attention may be directed to the large questions at issue rather than to those items which, particularly in illumination problems, should be given second place. When emphasizing relative efficiency and cost values, the average popular ideas regarding illumination problems are appealed to, whereas a distinct service

can be rendered the public by an educative tendency to divert public opinion from too great a consideration of petty cost differences in favor of the various factors contributing to illumination excellence.

MR. S. B. STEWART: (Communicated)—My experience with lighting systems has been confined strictly to those where artificial gas is the chief factor, and for this reason I cannot say much regarding methods of lighting by electricity.

I have felt for some time that the manufacturers of gas lighting appliances and the gas companies have been slow in taking advantage of the artistic features that might be obtained in the construction of their appliances. In fact, I have felt so strongly on this subject that I contributed an article entitled 'Neglected Opportunities' to *Progressive Age*; it was published in that magazine in the issue of December 15, 1911, page 1036.

The principal object of the gas companies has apparently been to give large volumes of light at small expense, without taking into consideration the desirability and efficiency, or the artistic effect of such method of lighting.

An idea that I have always held, is that lighting should be divided into three distinct classes, viz: residence lighting, office building and hotel lighting, and factory lighting or the illumination of large areas.

For residence lighting, the artistic should be blended with a pleasing efficiency. For this purpose, what could be better employed than the semi-indirect method. The direct method, of course, is also of value under some circumstances, as for instance, in case of reading lamps. Shadows are not an objectionable feature in residence lighting, in fact they are often of great advantage in producing desirable and pleasing effects. It should be remembered that the principal object in the lighting of a residence is not that every nook and corner of a room should be illuminated, but rather that all the features and furnishings of a room be subdued into one harmonious whole.

For lighting office buildings and hotels, or establishments of that kind, the indirect systems appeal strongly to my personal taste. Shadows are objectionable in office work if they become unduly prominent and are often hindrances to the employees

or clerks, sometimes resulting in damaged eyes; while a generally shaded area as produced by indirect lighting has a uniformity which seems altogether pleasing and comfortable to those who are working. While I have seen only two instances in office buildings were indirect lighting by artificial gas has been successfully installed, yet I am of the opinion that this method of lighting is practicable and of great value. In the two instances referred to, the clerks in the various offices have been more than pleased with the results and the managers have commented to me upon the greater efficiency of their clerical force and the better quality of work done.

For lighting large areas, such as factories, where a general illumination is desired and where the rays do not necessarily cause any eye strain, and where artistic effects are not primarily sought, my observation had led me to believe that direct lighting by means of large units is preferable.

Concluding, allow me to say that the field for all three systems is large. Each one has its advantages, and under certain conditions and circumstances is superior to the others. The principal aim should be to adopt the peculiar style most eminently fitted to the conditions to be met and make successful application thereto.

Mr. J. G. Henninger: There are two or three things about which I would like to speak. A short time ago when I was in New York I was going over the lighting situation with the members of a large reflector company and had an interesting bit of information brought to my attention. It shows how necessity is ever the mother of invention. Down through the Southern and a great many portions of the Northern states, where it is necessary to have a great many of these electric ceiling fans to keep the air moving, the problem of putting up the lights properly and still fiinding space for the fans is pretty big. A very common method of installing these units I found in a trip through the South was to have the fan unit hung down possibly eight feet above the floor and then have the light sources sticking out underneath the fan. You can all appreciate that as a rule it would make a pretty bad system of illumination.

A certain man in New England was up against this very proposition. He thought the matter over and asked some others what

they thought ought to be done. They didn't know. What did he do but go down to a corner hardware store and buy a big dishpan of bright new tin, and cut a hole in the bottom of it; then he placed it on the supporting stem of the fan. He next placed a number of clear lamps inside of the dishpan with the result that he had a splendid indirect lighting unit and a ceiling fan all in one. Now if he had attempted to use a direct lighting system with units above the fan on the same fixture he would probably have had trouble from flicker, but in this way that difficulty was entirely eliminated. It seems to me that his experience might be well kept in mind. Such problems come up frequently and surely it is a good thing to profit by the experience of others.

The point that was made with regard to diffusion and efficiency in residences is well worthy of a little bit of elaboration. I have met people who have shown a very great tendency to talk efficiency altogether in residence lighting. To the average man we do not want to talk efficiency altogether, but rather a combination of efficiency with pleasing effects. I think the two are entirely compatible. If we can get a very pleasant system of illumination with as high efficiency as possible with a decorative result, we will do well.

With regard to indirect lighting, I had the pleasure in the last few months of looking over quite a large number of indirect installations. I would say that in some cases the results were very pleasing. I could easily see how the employees worked with the greatest of ease under the illumination, and in others I found that I immediately wanted to shade my eyes when I got in; so I came to the conclusion that the relative brightness and the height of the ceiling had a great deal to do with the problem. With a ceiling of average height I found reading and looking around the room very comfortable. One could read in any portion of the room with the greatest of comfort. In a similar room where the ceiling was much brighter, the intensity of illumination being about double, I found that it was uncomfortable to look around. One could read fairly well, with the head bent down, thus shading the eyes. I believe that the brightness of walls and ceiling as well as their color must be considered carefully when a system of indirect illumination is to be used.

because discomfort is apt to result if they are not taken care of properly. I believe we are only beginning to realize how many things we have got to find out about indirect illumination.

The need for correctly designed fixtures in some of our large state capitols, churches and other public buildings, has been impressed on me on a number of occasions, one especially: There is a large church in Cleveland. The fixtures in this building are very beautiful, and entirely in harmony with the general lines of the architecture of the church; but the designers forgot that folks occasionally have to read a hymn book and occasionally want to look over the church calendar. These fixtures are large, probably eight feet high. The lamps in them are scattered in most any old way around a large central rod leading up through a cylinder of translucent glass. The illumination on the pew level is too low for comfortable reading. With a little judgment in design, the same artistic appearance could have been had and likewise an intensity of illumination sufficiently high for comfortable reading with no increase in power consumption. If a large lamp and reflector were placed in the base of the fixture, to insure proper direction of the light, and a few small lamps up through the center of the cylinder, the artistic effect would be equally good and the folks would still be able to read comfortably.

I think that we are gaining ground along this line because fixture manufacturers are beginning to realize that efficiency as well as effect must be considered.

Mr. S. G. Hibben: The ground has been so thoroughly covered by Mr. Henninger and the other speakers, that there remains just one point, and that is, that there are so many things to be taken into consideration other than just the foot-candle efficiency or whether the system is successful from the view point of a man's ability to see detail or not. We cannot decide the semi-indirect system altogether on that basis.

I agree with Mr. Millar's remarks about the fact that semi-indirect lighting, so far as ability to see detail work was concerned, was very good, but that sometimes it was very cheerless, and that if semi-indirect lighting or indirect lighting does not give a person a pleasing sense of enjoyment of his room, then by all means use the local lighting. I think the ideal system would be

a combination of these methods of lighting—with the semi-indirect or indirect method, and purely local illumination.

I think of another factor in that connection, and that is concerning the proportions of transmitted and reflected light; that these proportions must be determined not altogether from the viewpoint of scientific construction, but also artistic effect. The object is not only to illuminate but to please the senses from a decorative point of view.

PROF. H. E. CLIFFORD: In two of the educational institutions with which I have been connected, we have tried indirect illumination and compared it with more or less direct illumination, and there has been no question, in the minds of the student draughtsmen at least, that the semi-indirect was distinctly superior to the shadowless illumination. I have also been interested to ask the draughtsman in two of the larger manufacturing companies, the General Electric Company and the Westinghouse Company, in regard to this matter, and to the number of 50 or 60 they have told me that they distinctly preferred a shadow, in order to determine where to place their ruling pens or pencil points. It was absolutely necessary to have a shadow to determine when the ruling pen or the pencil point met the paper.

In regard to to the question of the percentage of direct lighting, I would like to say just a word as to the effect of a very high percentage of indirect lighting on the appearance of the ceiling. That point is referred to in the paper. I was not quite clear as to exactly what the writer had in mind in speaking of the appearance of the ceiling. It seems to me that if too high an illumination is placed on the ceiling, the natural tendency,—whether or not from a psychological effect I am unable to determine,—is to put the room out of proportion and also the ceiling; and if you notice a ceiling which is illuminated at the edges brightly and at the center with a much less intense illumination, you will find that ceiling gives the impression of curvature. The parts which are brightly illuminated are brought down lower. I took some forty odd students into a room with which they were not familiar and by illuminating the ceiling at different degrees asked them to judge the height of the room; and although the estimates of height varied somewhat, there was

distinct concurrence in a diminution of the height of the ceiling, brought about by an increase in its illumination. It seems to me therefore that one of the effects of too large a percentage of indirect light is to cause what I have always felt was a very sure resultant in the lowering of the ceiling due to the higher illumination.

Mr. David Crownfield: In regard to what the chairman said about shadows, I think it is one mistake the reflector people make, to claim shadowless illumination. I think any shadowless illumination is absolutely a mistake, but it is a mistake which can be remedied in the layout. Shadows can be obtained just as well with indirect illumination as with any other. That is shown where bands of foliation are run along the ceiling, care being taken so that the decoration along the ceiling stands out in a very pleasing manner. Also the coves around the ceiling may have their proper shadows.

Prof. H. E. Clifford: There is one point in regard to indirect illumination which has come to my attention within a few weeks in talking with one of the managers in one of our large department stores. In suggesting that certain indirect illumination be used for its artistic effect and also for the improvement in the general character of the illumination, I was met with the reply:

"It is to be remembered that the purchasing customer is attracted by a room which gives the effect of brilliant illumination—not so much to good illumination—and if we wish to sell our goods we must get the customer into a room where they are on exhibition; and no matter how artistic the room may be or how good the illumination, unless there is an effective brilliancy the customer does not get that spirit of fascination which is essential to purchasing." That is rather an interesting point, and I think it is true. The great majority of purchasers in our department stores are influenced by brilliancy,—no matter how bad the illumination may be. If you can hit them hard enough in the eyes you can secure their attention for a sufficient time. At all events that was the statement made to me by a man who has, I have found from an experience of some years, a good deal of engineering horse sense. In his opinion it was very difficult, as he

had seen indirect lighting, to get that effect of brilliancy which is essential to attract the customer.

DR. LOUIS BELL: I have been intensely interested in these three papers; first, because the subject itself is one of great interest to the illuminating engineer, and second, because these three papers are getting down to a reasonable scientific view-point. We have had heretofore a good deal of what you might call impracticability in the discussion of direct and indirect lighting, but in all three of these papers we have an approach to what is a real philosophical view of the situation; that is to say, you must adapt your lighting to the conditions you have to meet. That is the fundamental thesis, so to speak, of illuminating engineering; and it is the one we too often forget. It is human nature perhaps to seek a panacea whenever anything is to be done, and there is no such thing and never has been such a thing in any direction of research. These papers emphasize the fact that we are after results; we want to get them effectively, cheaply, and systematically, under all conditions. To do this the engineer has to vary the means which are employed to reach them.

As regards some of the points brought out in these papers, there is much to be considered, more than I have time to speak of here. But there are a few things to which attention should be directed. First, what is the chief complaint against direct lighting? It is the high intrinsic brilliancy in the eyes. Why do we get high intrinsic brilliancy in the eyes? We know perfectly well that it may be too high for the retina to endure with any degree of comfort. I long ago referred to this matter under the subject of visual usefulness. I think I know why it is that direct lighting is objected to on the ground of its high intrinsic brilliancy. It is not because we are using direct lighting at all. It is because we are using shades that are improperly designed from the standpoint of visual effectiveness; and the fault of the direct lighting shades, true of 95 per cent. of them at least, is that they do not shield the lamp. The average shade for a tungsten lamp is—at least for the ordinary sizes—1½ inches too shallow to hide the bright part of the lamp. I have talked to the makers of shades over and over again, but they do not seem to be enlightened. If

a number of our so-called standard shades were placed in a room of this size and one went to the back of the room, he would find every time that the light is shining in his eyes, either from the insufficiently frosted shade or from the bright filament itself.

I have talked to the lamp makers about their bowl frosting, too. I made a strenuous attempt some years ago, when we first got the tungsten lamps, to get them bowl frosted to a height that would do some good, and I was not able to do it. The lamp makers cheerfully responded that it was impracticable to frost the lamp high enough to conceal the filaments. When one gets a shade that actually fits a metallic filament lamp, that difficulty will be obviated almost entirely and direct lighting, so-called, will very closely approximate in its visual effectiveness the semi-direct light. So long, however, as the filament sticks out of the shade where it can be seen, there will be all the difficulties that have been alleged against direct lighting.

Now, again, suppose one considers the question of glare on the paper. I have a keen appreciation of that and have preached about it for a long time. What does it mean literally when one deals with the question of glare from the paper It means this, that with specular reflection the angle of incidence is equal to the angle of reflection and the point of incidence and the reflected ray are in the same plane. Now what happens when there is semi-specular reflection, as one may observe on highly calendered paper? Instead of a point reflection from the paper as in specular reflection, the light is distributed in a geometrical figure, roughly speaking perhaps a cone of reflection from the point on the paper, or more precisely in most cases it approximates, perhaps, an ellipsoidal cone. The result is that specular reflection is produced at practically the direct point of incidence of the light.

Now what happens when the filament of one of these direct lighting units is visible? One gets that particular kind of semi-specular reflection and he gets it hard. It undoubtedly is annoying. I do not think it does quite as much to the normal eye as is popularly supposed, but the average eye is not normal. Some oculists after carefully examining many thousand eyes found I believe, about four per cent. that were normal. At all events it is a comparatively small proportion; and if there is any trouble

with the eye, and there generally is, all these things are exaggerated. The trouble which we ascribe to bad illumination is very frequently due to small eye troubles which are not noticeable under ordinary conditions, but which crop out under bad conditions. When one comes to indirect lighting—multi-direction lighting—what happens? This: one does not get so much specular brilliancy from any one point as he got before; but on the other hand my observation is that he cannot find any place where he can dodge it. There is a certain amount of that specular reflection from all kinds of angles of incidence. If one is dealing with the normal semi-specular reflection from the surface, he can push his lamp to one side and he can dodge the cone of specularly reflected light which otherwise would come to the eye. If the large spot on the ceiling is very brilliant, it is very difficult to dodge that spot; so that while the intensity may be reduced it cannot be eliminated altogether, even with indirect lighting.

The statements as to relative efficiency of indirect, semi-direct and direct lighting which are here given are, I think, thoroughly conservative and I can confirm them from my own practise; but for all that the question is chiefly that of getting the light out of the eyes. With high efficiency there are conditions which are a little harder to meet. With low efficiency the conditions are somewhat easier to meet, but in no way can one get exactly what he wants. It is only a rough approximation at the best.

As regards the question of shadow, there is very much to be said. Strong direct shadows, particularly in the wrong direction, are very bad. Absence of shadow is equally so. Draughtsmen in particular complain bitterly about absence of shadow that are sometimes apparent with purely indirect lighting. They need a little shadow in order to locate their pencil points properly and see what they are about, and the same is true from an artistic standpoint. Rodin, perhaps the greatest sculptor of the last five centuries, in his interviews published recently, calls the sharpest attention to the value of shadows in bringing out the artistic points of a statue. He illustrates this by taking a candle in his hand and walking around one of the great masterpieces of Greece and showing the marvellous effects that the sculptor

attained in the slight elevations of surface, in the gentle rounded curves that were absolutely invisible under ordinary illumination, etc. From an artistic standpoint, therefore, shadowless illumination should not be demanded.

What is the moral of all this? The moral is that we must as engineers direct our attention toward getting the right kind of light for the particular purpose we have in hand. We can usually arrive at our result by any one of the three methods, but in order to do that we must first keep the light out of the eyes, and second, preserve something of the shadow effects. Now to what does this point? It points to a certain degree of semi-indirect illumination. We get this either with semi-indirect fixtures or even with direct fixtures. It is a rather surprising experiment to photograph an illumination which is lighted first by indirect, second by semi-direct lights with enclosed shades, and third by direct light. In each case there may be a strong indirect component. With the direct lighting there may be an illumination that would be very amazing to the average experimenter—with the semi-direct a little more—and with the indirect one might get almost a purely indirect illumination. The exact ratio between direct and semi-direct illumination depends upon the purposes for which it is to be used. All these three papers point, I think, more than anything else to the importance first of strongly diffused light, and second to the order of light chosen; not wholly indirect and not wholly direct. In other words it points away from the upturned opaque reflector and away from the opaque downward reflector, toward the more artistic and more uniformly distributed sources of light which may be found in various types of globes or bowls and in some indirect fixtures.

MR. P. S. MILLAR: There is one quality of indirect lighting which appeals strongly to the practitioner and which is well illustrated by a recent experience. In the office of a large lighting corporation are two rooms somewhat similar in character, each used for clerical work. In both various kinds of direct lighting systems are said to have been tried with poor success. In one, recently an indirect lighting system has been installed, and the clerks have reported entire satisfaction with the lighting. In the other, a system of direct lighting is still employed. The

arrangement of desks and lighting fixtures is suggested in fig. 1a The clerks are so seated with reference to the lighting fixtures that in no practicable position is it possible to avoid either glare due to specular reflection from the papers worked upon, or shadows occasioned by interference of the hands or head of the clerk with light coming from one or more of the sources. This combination of glare and shadow naturally occasions condemnation of the direct lighting system. A proper location and equipment

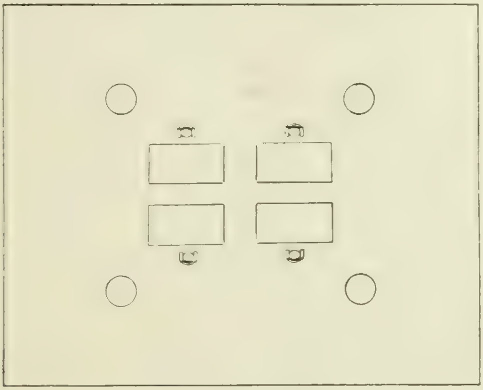


Fig. 1a.

of the light sources in the direct lighting system could minimize or entirely eliminate the difficulty.

The moral of this is that in nearly every instance where there is complaint concerning direct lighting systems, the cause may be traced to injudicious use or to neglect of some of the fundamentals of lighting. It is correspondingly true, however, that an indirect lighting system may be employed by the tyro with relatively little danger of encountering such difficulties as those which have been mentioned. This is a real merit which should not be neglected in considering the qualities of indirect lighting systems.

Mr. A. T. Sampson: I would like to know if anyone here knows whether the Curtis Publishing Company have discontinued their use of the indirect system.

Mr. David Crownfield: I can answer that. No, they have not. I would like to state that before the Curtis Publishing

Company installed indirect lighting in their offices, they made severe tests lasting over several months between the direct, semi-indirect and indirect systems, using the mirrored reflectors in the latter case. They took three sets of clerks and transferred these around, trying each set under the various systems. The Curtis Company had these clerks examined by physicians and oculists, both before and after they worked under each type of light, to find out just what the effects were upon them. A record was also kept of their efficiency. The company then took a vote of the employees as to which system they preferred. The result was that from an efficiency and health standpoint, and also from the standpoint of pleasure on the part of the employees, the Curtis Company decided to install the indirect system.

The same tests were tried by the architects in the case of the new building being erected here in Boston for Messrs. William Filene's Sons Co. and the indirect system has been decided upon for that building also. This decision was reached, I understand after rather exhaustive tests made under the supervision of the architects.

I think that as far as this whole matter of artificial lighting is concerned, it has been very strongly brought out in these various discussions that any particular problem needs to be very carefully thought over before it is decided whether the system adopted should be direct, semi-direct or indirect. I think all three of these systems have certain drawbacks and certain advantages, so that it requires very careful study before deciding which system is to be installed, and then a very careful study to properly install either of them. That has been my experience for some time.

I thoroughly agree with what Dr. Bell said about the position of the lamps in the shades. I think also that something will have to be done to slightly modify the color of the tungsten lamp. I know of a large church at Wakefield, Mass., in which was recently installed a direct system with tungsten lamps and flint depolished shades. The color scheme of the church went all to pieces; the carpet, a rich warm maroon, became a vivid turkey red. This objectional feature was overcome by dipping the lamps themselves and the shades in a slightly amber-colored mixture—

not such a coating as is generally used to dip lamps in, but using dry color and mixing it with a little turpentine, getting a satisfactory tone and then adding a little dryer. The result was very satisfactory, and the rich red carpet which the church had selected became its true color again.

The church was decorated by daylight and of course the color scheme held true. The light comes through stained glass windows, which scheme was also worked out by daylight. The carpet, of course, was made by daylight and was satisfactory under such light, but under the tungsten light it became a very pronounced turkey red, which was particularly at variance with the color scheme of the interior.

I think under the modern method of high efficiency units there has been too much concentration of light at one point and the light is too white in character. I think one of the advantages of the indirect system is that throwing the light, as it does, over a painted ceiling, it modifies the light and there is obtained a very much softer light than under other systems. I believe also that the seeing efficiency of the eye is much greater under the indirect system than it is with the other systems, with high efficiency shades, etc., turned directly downward. I am quite sure of this from data compiled from various sources, based both upon experience and observation.

THE PHYSICS OF LIGHT.*

BY GEORGE A. HOADLEY.

In a certain sense it is a thankless task to try to define anything but if one is to consider the physics of light he shall need to know what light is. The physicist makes short work of it by saying that light is a vibration in the luminiferous ether—the light bearing ether—of such a character that it is capable of acting upon the visual organs and producing sight.

The popular idea of light, and it has much to recommend it, is that the eye is needed as well as the ether wave and that a body is a light giving body when it can be seen. This second conception has little to do with ether waves but much to do with the results that are observed when these ether waves strike upon the right kind of matter.

As a matter of fact the only way in which an ether wave, or light wave, can make itself known to the eye is by passing directly through the pupil of the eye and striking upon the retina. This is true whether the source of the light wave is a primary source, like the sun, or a secondary source, like a mirror upon which the rays of the sun fall. This sounds like saying that rays of light are invisible, and is a hard saying when one thinks of the glory of light that surrounds him on a sunshiny summer day. A simple experiment will show whether it is possible for light waves to be invisible or not.

Figure 1 shows a box three feet long having glass ends and a

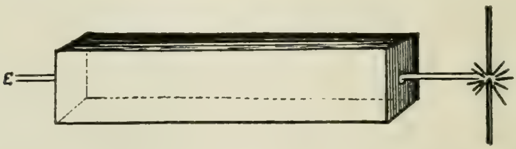


Fig. 1.—Box with a glass front for demonstrating the invisibility of light waves.

glass front. This box is filled with air that has been somewhat carefully freed from dust. A small projecting arc lamp is so placed as to throw a parallel beam of its light through one glass

* A paper read before a meeting of the Philadelphia section of the Illuminating Engineering Society, February 16, 1912.

end of the box and out at the other. When this lamp is turned on it will be observed that the beam can be traced before it enters the box and after it leaves it; but within the box there is no sign of light at all. If, however, the two cork stoppers that have been placed in holes near the ends of the box are pulled out and the ordinary air of the room is substituted for the dust free air, by blowing into one of the holes with a pair of bellows, the path of the beam at once becomes a luminous path inside the box, as well as outside. If in either part of the experiment the eye is placed at E, the beam at once becomes visible, showing that light is passing through the box, though there appears to be no light present when it is viewed from the side. An experiment of this kind is not at all needed to prove the invisibility of the ether waves, because if light waves themselves could be seen from one side, one should see the distant heavens aglow with light on any clear night and the only darkness would be that of the long slender cone caused by the shadow of the earth projected into space.

When bodies are studied with respect to their ability to transmit light, they are separated into three classes: first, a small class of bodies that transmit light with apparently little loss in intensity, like glass, mica, etc.; these are called transparent bodies. A second class is made of those that do not transmit light at all, like iron, wood, etc.; these are called opaque. The third class comprises the great majority of bodies that permit a certain amount of light to pass through them, like opal glass, paraffined paper, etc.; and these are known as translucent bodies. Many opaque bodies have to be placed in the latter class if they are made thin enough. A thin section of wood, for example, lets a great deal of light through, thus showing the character of the cells; and if a piece of gold leaf is held between two clear glass plates, objects can be readily seen through it. Everything, however is of a light green tint, since this is the only color that comes through.

The first experience that we have with light teach us that, as long as it is moving in a single uniform medium, its path is a straight line. This fact is generally made use of long before the reason for it is understood. A rifle ball is sent into the bull's

eye by sighting through the rear and front sights. A straight line is extended beyong two stakes by sighting to a third placed in the line of sight. Similarly one may see a man walk around a corner and lose sight of him until he, too, has made the same turn.

If the direction in which light moves were not in a straight line it would be impossible to form a picture on the wall of a dark room by means of the rays of light that come through a small hole in the wall of the opposite side. What is known as a pinhole photograph is made by replacing the lens of a camera by a thin metal disk, in the middle of which there is a small hole. The light from any source, passing in straight line paths through the pinhole, forms an inverted image of the source upon the

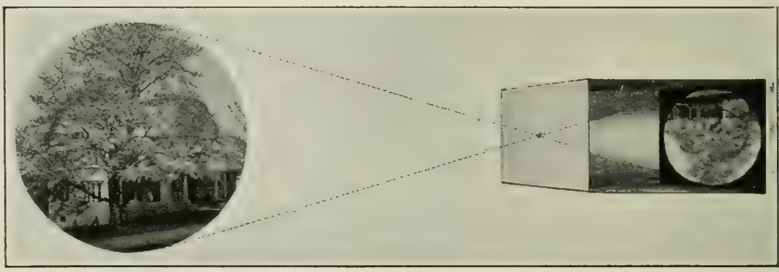


Fig. 2.—Illustration of the principle involved in the formation of a pinhole image on a photographic plate.

ground glass. This image is always in focus and its size increases with the distance between the pin-hole and the ground glass. By substituting a photographic plate for the ground glass, a negative can be made as with a lens. Figure 2 shows the principle of the formation of the image. Many a photograph has been taken by using a pinhole in place of a lens.

When the statement is made that the path of a ray of light is a straight line path, it is understood that this is only true when the medium through which it passes is of uniform optical density. This is equivalent to saying that the velocity does not change in passing through it. To say that one medium has a greater optical density than another, is the same as saying that the velocity in the second medium is greater than it is in the first, *i. e.*, the greater the optical density the less the velocity.

There is one path, and one path only, by which a ray of light can pass in a straight line from a medium of one optical density to another of a different density, and that is when the direction of the path is at a right angle to the surface of the new medium. At any other angle there is a bend, more or less pronounced, at the point where it enters the new substance. If a ray of light passes from air into glass, its path (fig 3) through the glass

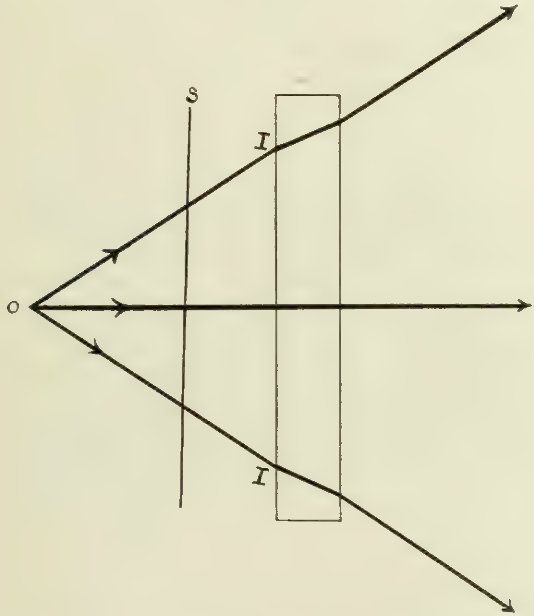


Fig. 3.—Illustration of the direction of light rays in passing from air through a medium (glass) of greater density.

will depend upon the angle at which it meets the surface. If an arc lamp sends its light against a screen in which there are three holes and the beam that passes through each is allowed to fall upon a piece of plate glass, the central beam, striking normal to the glass, will pass through in a straight line, while the others will be bent. Since this latter phenomenon is one without which nearly all the apparatus of the present day would be impossible, it may be well to consider the reason for it. The fundamental cause of this bending of the ray, or refraction, as it is called, is

that the velocity of light is greater in air than in glass. In a beam of sunlight the front of the beam forms what is known as a plane wave. When such a beam strikes a piece of plate glass (fig. 4) at an angle the side of the beam that enters the glass first is retarded, since glass has a greater optical density than air, so that when the front of the same wave, on the other edge of the beam, enters the glass the wave front will face in a new direction. This direction will be preserved in the path through the glass, but on emerging from the other side, a reverse change will take place and the beam will pass into the air in a path parallel to its original direction.

If, instead of sending the beam through a glass with parallel

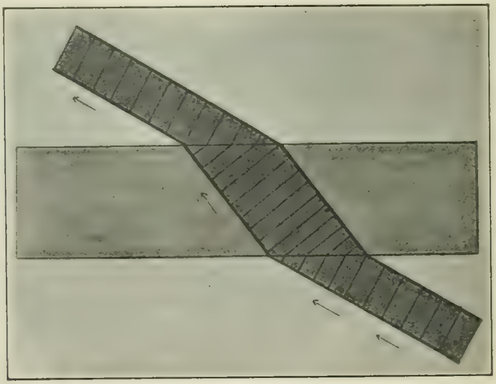


Fig. 4.—The bending of a beam of light in passing from air through a piece of plate glass, when the beam strikes the glass at an angle.

sides, it is sent through a triangular prism (see upper part of fig. 5), the ray will be bent, both where it enters the prism and where it passes out, in one direction only and that is, toward the base of the prism.

If two prisms are placed base to base (fig. 5) and rays pass from a light source to the face of each, the rays will meet at a common point on the other side of the prisms.

If one step further is taken and the surfaces are curved (fig. 6) a convex lens with a definite focus is the result.

In order to construct the path of a ray of light through any of these prisms or lenses, one must make use of the law of refrac-

tion. Snell, a Dutch mathematician, stated in 1621 that, for a given ray of light, the ratio of the sine of the angle of incidence, to the sine of the angle of refraction, is a constant quantity. This ratio

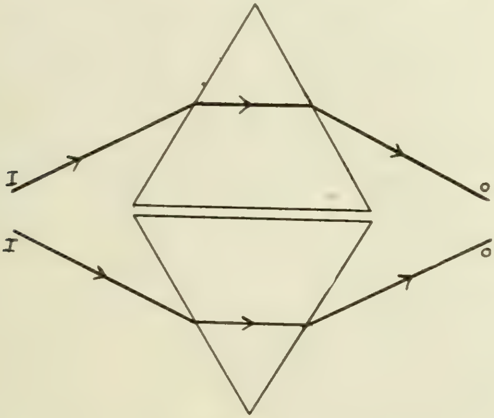


Fig. 5.—Direction of rays of light in passing from air through glass prisms.

is called the index of refraction and the same law can be derived by a comparison of the velocities of light in the two media. Suppose sunlight to fall upon a screen, S, fig. 7, to pass through an aperture in the screen and to strike upon the surface of a piece

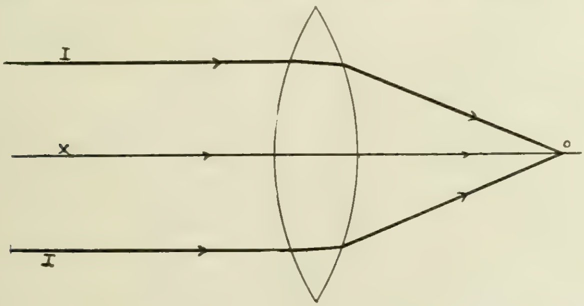


Fig. 6.—Directions of light rays in passing through a double convex lens.

of glass A B. When the beam of light strikes at C, the wave front is C. E. and the other side of the beam will strike the surface at D, a certain short time afterward. During this time the beam entering the glass at C, has gone a distance C H and the wave front now becomes H. D., E. D and C H being the

relative velocities in the two media. The angle of incidence, I, is equal to the angle I′, between the wave front and the surface of the glass at C D while the angle of refraction, R, is equal to the angle R′ between the new wave front in the glass and its surface. Now D E is the sine of the angle I′, or its equal I, the angle of incidence and C H is the sine of the angle R′, or its equal R, the angle of refraction; hence the ratio of the respective velocities in the two media, which is a constant quantity, is the same as the ratio of the sine of the angle of incidence to the sine of the angle of refraction and hence this ratio must be a constant quantity.

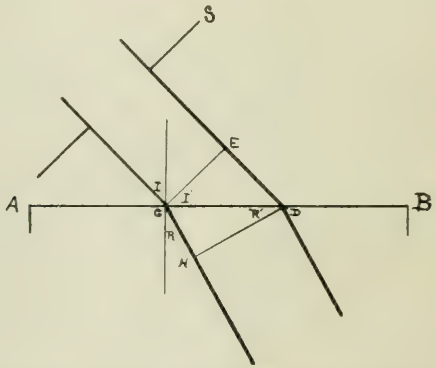


Fig. 7.—Determination of the index of refraction by a comparison of velocities.

Since a ray of light, that passes from an optically rarer medium into one that is optically denser, is bent towards the perpendicular, it is evident that rays coming from the air and striking the surface of glass or water at any angle, will pass through the surface and enter the new medium. Now what will happen if the ray passes from the denser medium into the rarer? Suppose light to come from a point, P (fig. 8) on the bottom of a glass dish nearly full of water. A ray normal to the surface, as P N, will pass into the air without change of direction. A ray, P B, making an angle with the normal, will be changed in direction at B, bending further away from the normal and will take the path B. E. The direction of this path may be found by multiplying D C, the sine of the angle of incidence by the index of refraction of water to air, or 4/3. This gives a distance

which, laid off at F E as the sine of the angle of refraction, determines the direction of B. E. If other rays, making greater angles with the normal are taken they will pass out into the air, bending farther and farther from the normal until one ray is found that just skims along the surface of the water, as M V. This is the ray, the sine of whose angle of incidence multiplied by the index of refraction is equal to unity and this makes the angle of refraction ninety degrees.

But what happens to those rays that make a greater angle of incidence than N P M, which is called the critical angle and

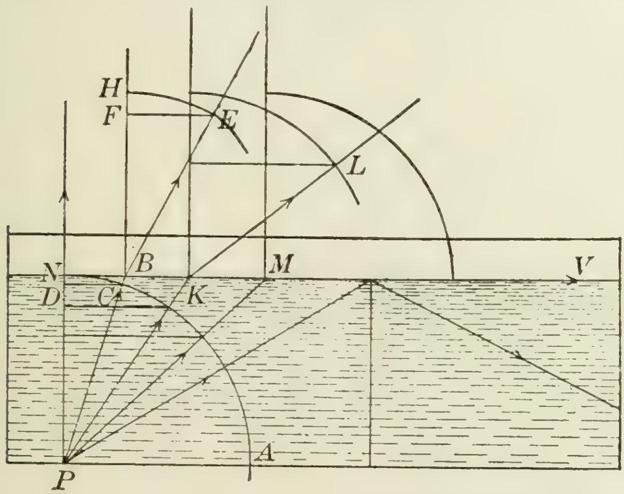


Fig. 8.—Direction of a light ray in passing from a dense through a rarer medium.

which, for the ray passing from water to air, is about 48.5 degrees? An examination of the figure will show that all rays making a greater angle of incidence than the critical angle are reflected back into the water, following the law of reflection from a plane mirror. This means that a fish on the bottom of a pond must see the entire 180 degrees of the sky compressed within an angle of about 97 degrees; in other words the entire sky appears as a circle bordered by the dark reflection from the bottom of the pond. Trees and buildings surrounding the pond appear to point toward the center of this circle and are much distorted.

Another result of refraction is that a body of water appears to be shallower than it really is. Rays coming from the bottom and striking the surface at points near together enter the eye. If these rays are projected from the eye back into the water, the point from which the light comes will appear (fig. 9) to be

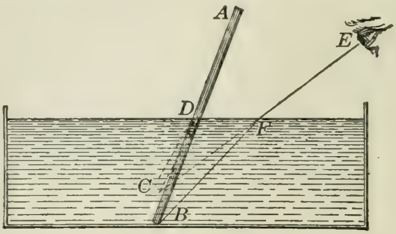


Fig. 9.—Showing how the bottom of a dish containing water appears to be raised.

nearer to the surface than it really is. This change in apparent position will be greater as the inclination of the ray from the normal increases; that is, the more slanting the direction in which an observer looks into the water the nearer will things lying on the bottom appear to be to the surface.

It is evident that a necessary result of the fact that the velocity of light is less in some media than in others, and consequently that there is such a thing as a critical angle, is that the surface that separates two perfectly transparent media is completely opaque to rays of light that strike it from certain directions. This is well shown by the use of the right angled prism (fig. 10) for

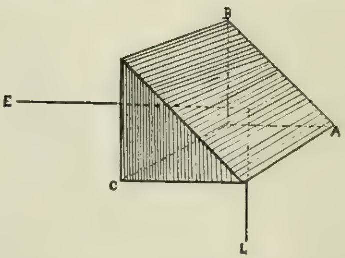


Fig. 10.—Illustration of the critical angle of a glass prism.

light than enters normal to one face, strikes the hypotenuse at an angle of 45 degrees, which is greater than the critical angle of glass to air, and is totally reflected in a direction normal to the

third face. All the light falling perpendicularly to the face A C will pass out the face C B. If a person, standing at E, looks towards the face C B, nothing can be seen except what is reflected from the direction of L., in fact a prism of this kind is the most perfect of reflectors and is used in many physical and atronomical instruments for this purpose.

An interesting illustration of the effect of total reflection may be shown as follows. A tank (fig. 11) having a small round opening on one side near the bottom is filled with water. Opposite to the opening, on the other side of the tank, is a plane glass window. When this opening is uncovered the water will flow out in a smooth stream. On putting an arc lamp back of the glass window and bringing the light to a focus upon the opposite open-

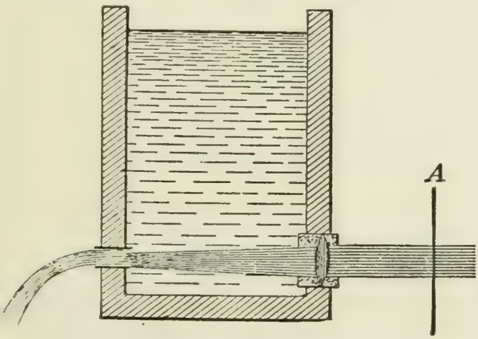


Fig. 11.—Total reflection of a light ray which follows the curvature of a stream of water from a vessel.

ing by means of a lens, the beam will be seen to keep within the stream for its entire length. The bright points at which the reflection takes place can also be seen on opposite sides of the stream. This phenomenon of total reflection can also be observed by bending a glass rod, with smooth ends, through a quarter turn and pointing one end at a source of light. On looking at the other end it will be seen to be brightly illuminated. A bent glass rod of this type is sometimes used to concentrate light upon the stage of a microscope when it is difficult to bring the light into the right position in any other way.

The fact that light will pass from air into glass, at any angle whatever, is of great importance in the lighting of rooms

by daylight, in buildings located on narrow streets. This is especially true whenever there are high buildings on the opposite side of the street. In such a case the only sky light that can enter the windows is from above the tops of these buildings, frequently coming from an angle from forty to sixty degrees above the horizontal. If plane glass is used in the windows, the light is all thrown upon the floor a few feet back of them, where it is of little value in lighting the rooms. By the use of prism shaped glass in the windows, however, total internal reflection can be made serviceable in throwing the sky light far back into the room.

An important application of total reflection is in the Lummer-Brodhun prism used in photometrical measurements. An ordinary form of sight box is shown in fig. 12. Light from two

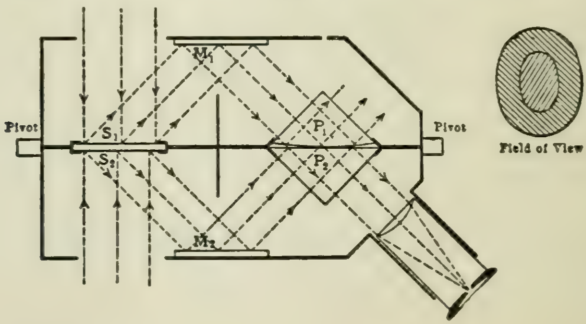


Fig. 12.—Plan of the Lummer-Brodhun photometer.

sources strike upon opposite sides, S_1 and S_2, of a white disk. From this disk it passes to mirrors M_1 and M_2 respectively. From these mirrors it is reflected to the compound prism, which consists of two right angled prisms having the face, which forms the hypotenuse of the prisms, ground away, except a small spot in the center, where the surfaces of the prisms are in close contact. The light from M_1, that strikes the central surface, passes in a straight line to the eye-piece, while the outer ring of light is totally reflected in a direction at a right angle to its former path. The light from M_2, falling upon the central surface, passes through in a straight line into the frame of the instrument, while the light that falls upon the outer circle is

totally reflected into the eye-piece and is seen as a ring of light around the central area lighted from M_1.

An improved form of the sight box replaces the mirrors M_1 and M_2 by right angled, totally reflecting prisms and also adds

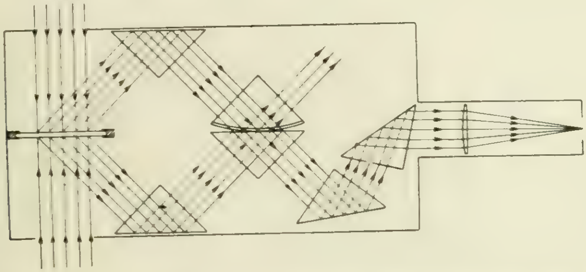


Fig. 13.—Plan of Lummer-Brodhun photometer with an improved sight box.

two others that make it possible to read the screen by looking directly across the photometric bar, instead of at an acute angle. This form of sight box can also be rotated on a horizontal axis, making it possible to receive the light of the standard lamp on S_1 and the light of the lamp to be measured on S_2, or vice versa, which is a great convenience in avoiding errors.

One of the natural phenomena that is due to refraction is the flattening of the disk of the sun on rising (fig. 14). This can

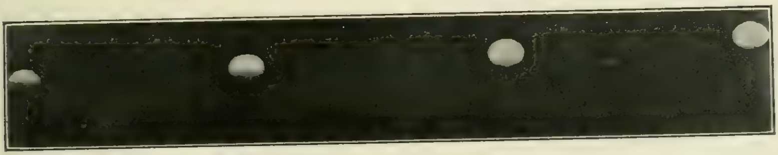


Fig. 14.—Pictures of the sun rising, indicating how its flattened appearance at the horizon gradually becomes round as the suns gets higher.

be seen best from some high building, having an eastern horizon not much above sea level. Since the density of the atmosphere decreases, from a maximum at the surface of the earth, to zero at its upper limits, light entering it from the sun will be bent downwards by decreasing amounts from the bottom to the top. The practical effect of this is to elevate the ray by about half a degree at the horizon, so that, as this is the angular diameter of the sun, one actually sees its entire disk above the horizon, when

a line drawn tangent from his position, would pass entirely above it. This apparent flattening of the sun's disk is caused by the greater bending of the rays that come from the lower side of the sun, since they pass through the denser portions of our atmosphere. Fig. 14 shows four of a series of seven photographs of the rising sun, taken at short intervals on the same plate. These show that as the sun rose above the horizon the flattening effect became less. If the change in the density of the air is not uniform, from the surface of earth upward, the outline of the sun is distorted in various ways. This is shown to a marked extent in photographs taken in California when the sun was setting over the Pacific. The layers of air of different densities near the water give rise to strange distortions that sometimes separate the disk into detached parts.

By holding a lighted match or burning an alcohol lamp in the beam of a projecting lantern the distorting effects of layers of different density in a transparent gaseous medium can readily be seen. These distorting effects of heat waves upon the line of sight in air are sometimes very troublesome to engineers who find it impossible to run a correct level line over land that is heated by the rays of the sun. The line of sight is no longer a straight line on account of the distortions produced by the changing density of the air.

From theoretical considerations it can be shown that the velocity of light in refracting media is inversely proportional to the refractive index of the medium. Since this is different for different colors, there is a corresponding difference in the velocities of the various colors. This is practically the same as saying that the velocity of light in a refractive medium is a function of its wave-length.

Suppose that a beam of white light strikes squarely upon the end of a block of glass twenty miles thick. The velocity through the block would be less than through the air and not only that, but the colors of the beam would be retarded differently. The red, with the longer wave-length, would be retarded the least, and the violet, with the shorter wave-length, would be retarded the most. While the time taken in passing through the block would be exceedingly short, the red ray would come out of it

3.8 miles ahead of the violet. This is shown diagrammatically in fig. 15, the spaces between the vertical lines representing the distances that each color would lag behind the preceding color, taken in the spectrum order from the red to the violet. If a drawing were made by adding the colors in the proper order to the red ray that comes out first, an idea would be obtained of the colors that would result from each one joining those that had preceded it. While it is impossible to demonstrate this experimentally, on account of the short time that it would take to pass from the red to the white, it is possible to show that there is no change of velocity due to a change of wave-length in the ether of that part of space which is immediately around the earth.

The distance of Jupiter from the earth is so great, that it takes thirty-five minutes for its light to reach us. At the end of an eclipse of one of its moons the first flash of light that comes

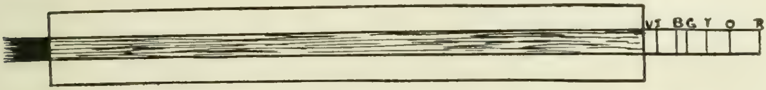


Fig. 15.—Graphic illustration of the retardation of the colors of a beam in passing through glass.

past the edge of the planet would be red, if there was an appreciable retardation in the velocities of the different colors. As a matter of fact the first flash of light is ordinary white light, without a suggestion of red, hence it appears that the visible spectrum waves travel with equal speed through the ether.

In the preceding discussion on refraction, it has been assumed that monochromatic light has been used, that is, light of one color or wave-length. If white light is used instead, the results will be more complicated and more interesting. As a result of the different amounts of slowing down of the velocities of the different colors, a beam of white light will, on passing through a prism, be separated into the spectrum colors. Since the red ray is slowed down the least, the direction of its path will change the least when entering and emerging from the prism and the violet the most. Fig. 16 shows the dispersion, as it is called, of a beam of white light on passing through a glass prism. If the light, after passing through the prism, falls upon a white screen,

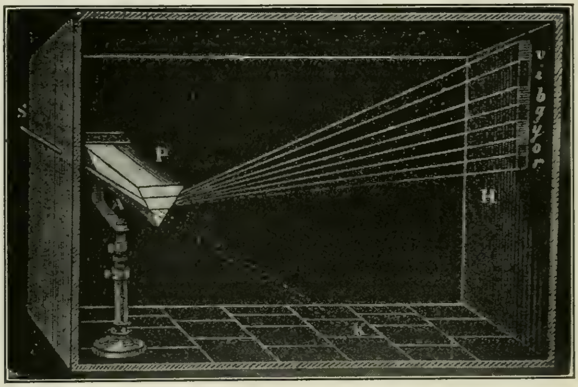


Fig. 16.—Separation of the component colors of a beam of light.

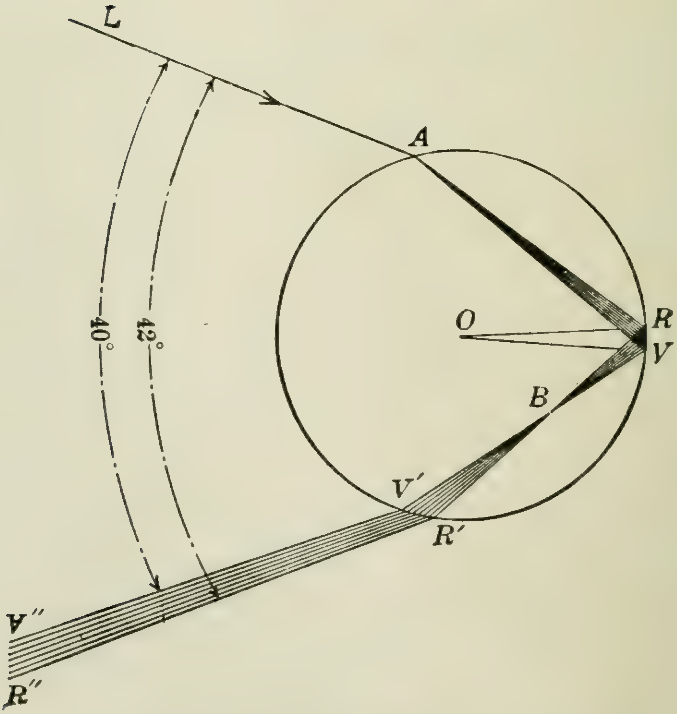


Fig. 17.—Graphic representation of the formation of the colors in a rainbow.

the result is a band of spectrum colors which change imperceptibly from the red to the violet through the whole list of rainbow colors and in the same order.

The rainbow is one of the most beautiful of the color phenomena of Nature. The conditions for producing it are that the rain be falling, that the sun be shining upon it, from a point not much above the horizon and that the observer shall be standing with his back to the sun. Each raindrop sends back through space a tiny solar spectrum. The rainbow is the combined resultant of the spectra from the different drops. To trace the formation of the spectrum from a single drop, assume that L A

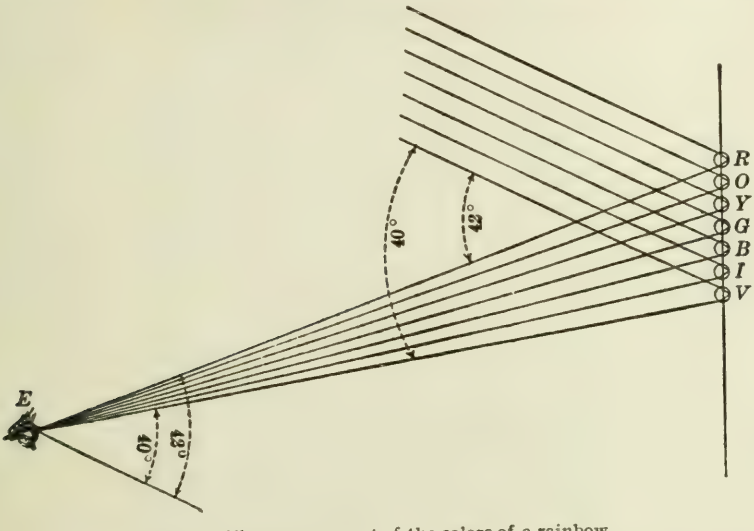


Fig. 18.—The arrangement of the colors of a rainbow.

(fig. 17) is the incident ray of sunlight. At A dispersion takes place and a spectrum is formed on the back of the drop at R V. By the law of reflection, these rays are sent back along the paths R R′ and V V′, crossing each other at B, and pass out of the drop in the direction R′ R″ and V′ V″. The angle between the ray (fig. 18) which enters the drop and the red ray that leaves it is 42 degrees while the angle between the entering ray and the violet ray is only 40 degrees. For this reason the observer receives the violet ray from a drop that is at an angle of 40 degrees above the axis of the bow while the red ray comes from

an elevation of 42 degrees, thus causing the red part of the bow to be on the outside.

Many devices have been used to represent the rainbow artificially. The one to be used in my lecture to-night is in the form of a glass cone. Fig. 19 shows the paths taken by two parallel

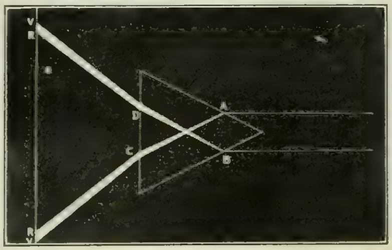


Fig. 19.—How an artificial rainbow may be produced on a screen.

rays falling upon the conical surface. It is seen that they cross within the prism and emerge with the red ray on the inside. By letting a beam of light from either the sun, or a projecting lantern, fall upon the prism, there is thrown upon the screen the appearance of a complete circular bow, the order of the

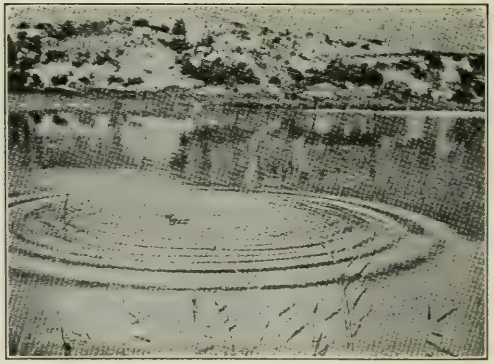


Fig. 20.—An illustration of wave formation. (Fleming.)

colors, however, being reversed as in the secondary rainbow.

If one stands on the edge of a quiet pond and tosses a pebble far out, so that it will drop nearly vertically into the water, a group of circular waves (fig. 20) will set out from the splash

of the stone and run to the edge of the pond, gradually diminishing in intensity. If now, when the surface is again quiet, two pebbles are tossed in so that they will strike the water at the same time, a little distance apart, the two sets of waves (fig. 21) will cross each other, each modifying the other in form. If a certain particle of water is lifted by both waves at the same time it will rise twice as high as though a single wave acted upon it; but if one wave tends to raise the particle and the other wave tends to lower it to the same extent, the result will be that it will not move at all. This means that at the place occupied by the particle total interference has taken place and a condition of rest results, the wave form being destroyed. If the two oppo-

Fig. 21.—An illustration of interference of two series of waves. (Fleming.)

site tendencies are not equal in intensity, a partial interference only will take place.

A careful study of the behavior of ripples on the surface of a liquid, has been made by J. H. Vincent. The ripples were set up at two points on the surface of mercury, by means of the vibrations of two pointed wires that touched the mercury surface at each vibration. A photograph (fig. 22) taken after the trains of waves had been set up, shows by the white lines the points at which interference took place, the dark lines showing either where the waves were strengthened, or where they were undisturbed.

If a wave pulse is set up in a long spiral spring, by striking it lightly near one end, the wave will run to the other end and

then be reflected back along the spring. If now, just at the instant that the reflected wave starts back, the spring is struck again, the second wave sent out meets the reflected wave in the middle of the spring, interference takes place and the wave form is destroyed at that place.

If a tuning fork is sounded over a resonating jar, there will be decided strengthening of the tone of the fork when the jar is of the proper length. On turning the fork until its edge faces the opening of the jar, interference takes place and the tone can scarcely be heard. If two tuning forks that give the same number of vibrations are sounded together their tones will be in perfect unison and will strengthen each other. If, however, a

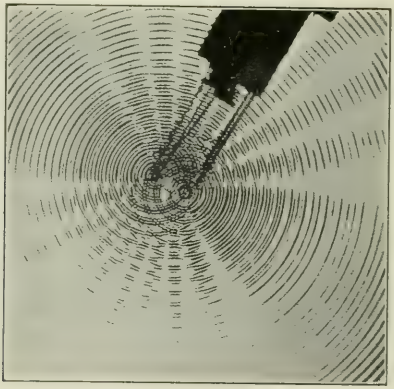


Fig. 22.—Photograph showing the points of interference of two series of waves.

small weight is attached to the prong of one of the forks, the rate of its vibration will be decreased and, on being sounded with the other fork, a succession of beats will be heard, the interference of the sound waves being noted by the absence of sound and vibrations in the same direction, by the intensified sound, or beats.

It is thus seen that interference in water waves and in the waves sent over a spiral spring, produces rest at the point of interference and that interference in sound waves produces silence. Does interference take place in light waves and if so what is the result? In order to investigate the matter and answer the question from the experimental standpoint, Fresnel devised a piece of apparatus (fig. 23) consisting of two mirrors, one fixed

and the other movable about an axis in such a way that its surface could be brought into the same plane as that of the fixed mirror. On sending light from a point source to the two mirrors,

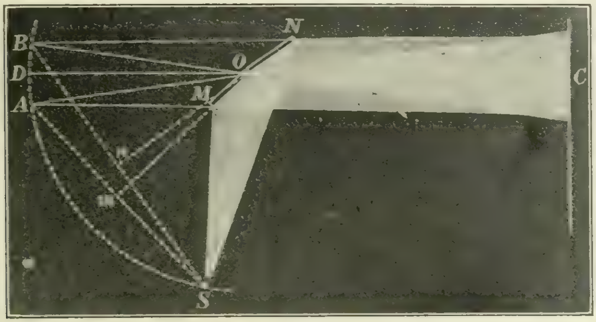


Fig. 23.—Diagram of Fresnel's apparatus for studying the interference of light waves.

the reflected rays cross each other and in the field of the screen on which they fall, a series of alternate dark and light bands may be seen. By finding the images of the point S, in each of the mirrors, N O and M O, it is evident that the light striking the screen is the same as though it came from the points A and B.

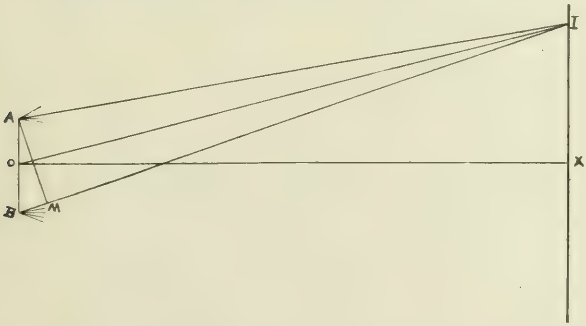


Fig. 24.—Explanation of the formation of bands on a screen when rays of light from a source are crossed after being reflected from the mirrors in Fresnel's apparatus.

The explanation of the formation of the bands may be given as follows: Suppose the two sets of waves start from the point sources A and B (fig. 24) and reach a point X on the screen, equally distant from each. Since the light waves start from

their sources in the same phase, these sources being the image of the point S, they will reach X in the same phase and, hence, reinforce each other and produce a bright band. If, however, two paths, that differ from each other by a half wave-length, are selected, such as A I and B I, they will reach I in opposite phases, will interfere with each other, and a dark band will be the result. From the construction of the figure, it is evident that OX : IX = AM : BM. But OX is the distance between the mirror and the screen and IX is the distance from the middle of the bright band to the middle of the first dark band. AM is the distance between the images A and B, since AB is practically equal to AM and BM is one-half the wave-length, L, of the color used. This gives $\frac{1}{2} L = \frac{IX \times AM}{OX}$, or $L = \frac{2 \times IX \times AM}{OX}$, and by substituting the numerical values of IX, AM and OX, the wave-length is determined.

Another form of apparatus (fig. 25) for the production of

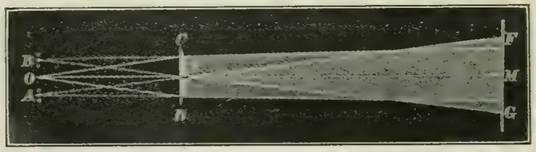


Fig. 25.—Diagram of another form of apparatus devised by Fresnel for the study of light wave interference.

interference fringes, which was also devised by Fresnel, is the bi-prism. By the use of this prism interference is produced by refraction instead of by reflection, as in the Fresnel mirrors. The bi-prism is one in which the angle at E, in the figure, is obtuse, while the two angles C and D are very small acute angles. When light from a narrow slit, at O, strikes the prism, that falling on the upper half is bent downward and after emerging from the prism appears to come from B. The light falling on the lower half is bent upward and appears to come from A. The appearance of these bands upon the screen is similar to that of the bands formed by the Fresnel mirrors, there being a bright band at M and on both sides of M alternate dark and bright bands. The separation of the bands, for a given screen distance,

depends upon the color, that is, upon the wave-length of the light used; those produced by red light are farther apart than those formed by blue. Fig. 26 shows the arrangement of these bands when received upon a photographic plate.

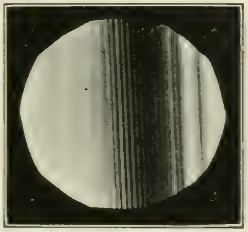


Fig. 26.—The bands as they are shown on the screen of Fresnel's apparatus.

In order to use interference bands as a means of measurement, Jamin devised a piece of apparatus which he called a refractometer. This device (fig. 27) consisted of two pieces of plate glass of equal thickness, silvered on one side, so supported that the distance between them could be varied at will. One of these plates, AB, is fixed while the other, CD, is provided with adjusting screws, by means of which it can be brought into exact

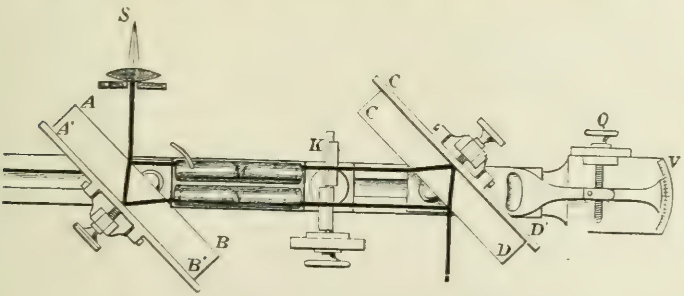


Fig. 27.—Diagram of a refractometer devised by Jamin.

parallelism with AB. A ray, striking upon the front face of AB, separates into two, one reflected and one refracted. The reflected ray passes to CD, then through to the silvered surface on the back, where it is reflected. The part of the ray from S that is refracted in AB, passes through to the silvered surface, where it is reflected and, passing out the front surface of AB, it is also reflected from the face of CD where it joins the ray

6

reflected from the back of CD. When the mirrors are parallel to each other, the paths of the two rays are equal in length and there is uniform illumination and no fringes. When the screws regulating the position of CD are turned, fringes appear and their number can be counted in the eye-piece of the instrument. One of the uses to which Jamin put this apparatus was to determine the refractive indices of gases. These were inclosed in tubes and inserted in N or M and the apparent change in the length of the path was compensated for by K, which consisted of two thin wedges of glass which could be made to slide over each other by a measured amount and thus introduce different thicknesses of glass into either path.

The most modern instrument of this general type is the interferometer (fig. 28) devised by Professor A. A. Michelson for

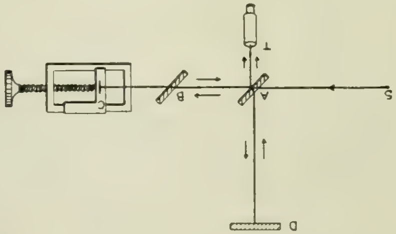


Fig. 28.—Diagram of a modern interferometer devised by Prof. Michelson.

use in the Michelson and Morely experiment for investigating the relation between the velocity of light and the movement of the earth in its orbit through the ether. The diagram shows the parts of the apparatus in their relative positions and the path taken by the light from S, until it strikes the eye through T. A and B are of equal thickness and are cut from the same plate of glass and are half silvered on one side. Part of the ray passes to the mirror D and returns and part to the mirror C and returns. Since the ray, going to D, passes twice through the thickness of the glass A, the glass B must be placed in the path AC, so that when this path is equal in distance to AD, the two paths shall also be optically equal. A, C and D are in truly vertical planes and D is capable of movement in the direction AD, in such a way that the plane of AD shall always be parallel to itself.

In order to secure this parallelism of D in all positions, the ways, EF (fig. 29), upon which the carriage carrying D runs, must be accurately ground and, in order that the distance through which D passes, may be correctly measured, the screw moving the carriage must be uniform in pitch along its entire length. This screw, generally has twenty threads to the centimeter, the micrometer head, M, has one hundred divisions and the head W, of the endless thread which turns M, fifty divisions. By these means the position of D can be read to the ten-thousandth of a millimeter while estimations of a hundred-thousandth of a millimeter can also be made. The practical meaning of this is, that the wave-length of light can be used as the basis of the measurements of lengths and its application to the measurement

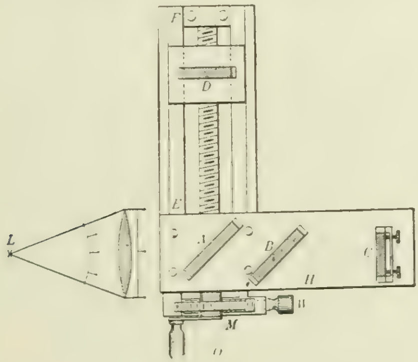


Fig. 29.—Diagram of Michelson's interferometer.

of such physical constants as the coefficient of expansion becomes apparent.

The phenomena of white light giving colored bands is well seen in Newton's rings; in a film of oil on water; in a crack in a piece of ice and, perhaps best of all in the projection of a soap film, or of a soap bubble on the screen with the lantern.

An early objection to the wave-theory of light was made on the ground that if it were correct, there would be a bright spot in the middle of the shadow cast by a disk placed in the path of a beam of light. The contention was that if light was propagated by means of waves, each part of the edge of the disk would be a new source of light and that at some point behind the disk

these new waves would strengthen each other and produce a point of light. As this had never been observed, it was stated that the wave theory could not be correct. This contention was correct and there is a bright spot of light in the middle of the shadow cast by a circular disk. There are, however, certain conditions that must be fulfilled in order to find it. The source of light must be nearly a point source; the edge of the disk must be smooth and a lens should be used to observe the spot of light.

What is known as a zone plate verifies in a striking manner the wave theory of light. Figure 30 is a picture of a zone plate,

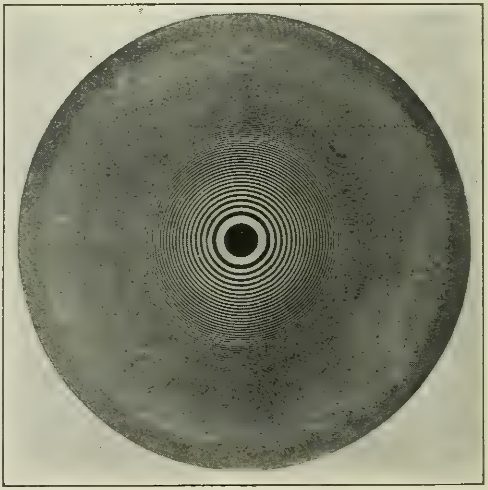


Fig. 30.—A zone plate.

taken from a drawing in Wood's Physical Optics, from which the following quotation is made: "If we describe on a large sheet of white paper circles, the radii of which are proportional to the square roots of the natural numbers, we shall have very nearly an exact drawing of the zone system, etc. If now we blacken the alternate rings with ink, and take a greatly reduced photograph of the whole on glass, we shall obtain a device which will enable us to screen off the alternate zones on the wave-front. Suppose we intercept a plane wave with such a plate and consider the illumination at a point so situated behind the plate that the

central circle of the plate corresponds in size and position to the first zone on the wave-front. The black rings stop all the secondary disturbances from the alternate or odd zones, which previously neutralized those coming from the even ones, consequently all the secondary disturbances, coming from that portion of the wave-front covered by the plate reach the point in the same phase, and the illumination will be very intense. The whole surface of the zone plate will send light to the point, the action being very similar to that of a convex lens. The distance of the illuminated point from the zone-plate we may speak of as its focus, and we readily see that the smaller the zones the shorter the focal length."

The similarity in appearance between the zone-plate and Newton's rings is at once evident on comparing them. The rings in both are on the same scale and a photograph of Newton's rings can be used as a zone-plate.

A somewhat similar effect is obtained when light from a slit passes a thin wire. On examining the shadow of the wire on a white screen, it will be seen that within this shadow there are a number of colored fringes, running parallel to its length.

In the case of light passing through a narrow slit, there will be the same play of fringes, in the shadow cast by the opaque sides of the slit. A photographic plate that has been exposed to sunlight and developed will have a uniformly black surface. If a sharp, narrow line is drawn through the film, as with the edge of a knife blade, and the plate is held close to the eye, diffraction bands appear when one looks at the sky, the screen in this case, being the retina of the eye.

If, in place of a single slit, a system of narrow slits is used, the phenomena become more pronounced, the fringes from sky light being highly colored. If the number of slits is sufficiently great, as in the case of a glass plate having several thousand lines ruled on it with a diamond point, a brilliant spectrum can be produced. If a grating of this kind is held close in front of the eye, and a strong light is viewed through it, a beautiful series of spectra will be seen on either side of the center. An arc, or even an incandescent lamp, on being viewed through a silk handkerchief or umbrella, will show a decided play of spectrum

colors. If a grating is placed in the beam of light from a projection lantern an image of the slit will be thrown on the screen composed of white light, and on each side of it there will be a series of brilliant spectra, having the blue end on the inside near the slit image. The spectrum obtained from a grating is called a normal spectrum, and differs from the spectrum formed by a prism, the difference being, that the positions of the Fraunhoffer lines, or of bright spectrum lines, in this spectrum, is proportional to their wave-lengths, while in the ordinary spectrum they are not directly proportional. The practical advantage of this is, that the scale of the spectroscope can be made up of equal divisions, so that the positions of lines that fall between these divisions can be more accurately determined.

I am well aware that but few of the many phenomena of light have been touched upon in this lecture, but as the subject was to be considered in a single lecture, the omission of many of its interesting phases seemed unavoidable.

THE ESSENTIAL PRINCIPLES OF ILLUMINATION.

2. CANDLE-POWER.*

Consider the light flux proceeding from an ordinary lighted candle. It passes in all directions except directly downward; but it is not uniform, for all the flame is not of the same intensity nor is the area of the source when viewed from different directions the same. The flux upward is less than a quarter of that out horizontally from the side. The flux horizontally is fairly uniform in all directions around the flame. Now assuming some way to determine the amount of this uniform flux, or its amount per unit area at a chosen distance, a standard is secured upon which to base measurements. A light has one candle-power if it delivers light flux per unit area at a chosen distance the same as that from a candle. At this same distance if the light flux per unit area from the source is sixteen times as much as from a candle, that source is 16 candle-power; while if the light flux from the source is not uniform, it is said to be 16 candle-power in the direction investigated.

Most light sources do not deliver uniform light flux around them; their candle-power is different in different directions. Thus an incandescent electric lamp with a simple hairpin-shaped filament placed so the lamp tip is downward will have a horizontal candle-power nearly uniform, except where the light flux from one leg of the filament is intercepted and cut off by the other because it is hidden behind it. (Light flux, and hence candle-power, is proportional to the area from which the light comes.) The end candle-power will also be much less than the horizontal candle-power. It is easy to see this experimentally by observing the amount of light flux which reaches a surface from the side or the end of such a lamp, in turning the lighted lamp so that a selected surface is lighted first by flux from the side and then from the end of the lamp.

In order to understand easily the flux distribution around any

* The second of a series of five talks (1. Light and light flux; 2. Candle-power; 3. Shades and redistribution of light; 4. Units of illumination and its calculation; 5. Principles of photometry) delivered at meetings of the Philadelphia section of the Illuminating Engineering Society, by Prof. Arthur J. Rowland. Talk No. 1 was published in the February *Transactions* at which time illustrations for it were unavailable.

lamp, curves of candle-power distribution are plotted. To try to make clear what such a curve is and how it is made, I have plotted one, fig. 3, for a lighted lamp for which the candle-power

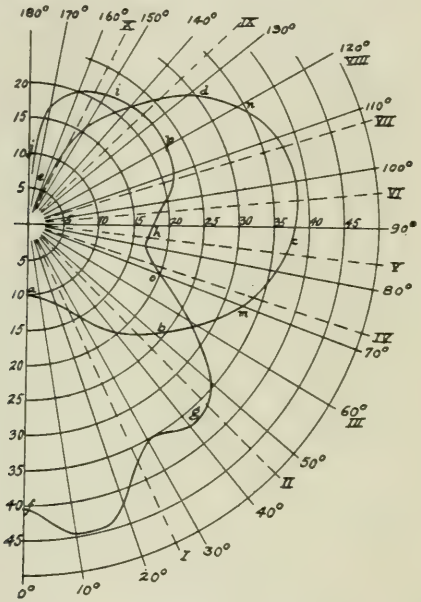


Fig. 3.—Plot of candle-power distribution around a light.

values have been previously determined. The light chosen is a 40-watt bowl-frosted tungsten lamp placed tip downward (base upward) so that the axis of the lamp is vertical. The experimental readings of candle-power are:

Deg.	Candle-power	Deg.	Candle-power
0	10.0	90	38.1
10	10.6	100	38.7
20	11.9	110	37.6
30	15.0	120	34.2
40	19.9	130	29.3
50	24.0	140	22.0
60	28.3	150	15.8
70	33.0	160	0.0
80	36.1		

From an ordinary electric incandescent lamp filament burning at a certain intensity (brightness) the total light flux must be the same no matter into what form it is shaped or curled. But the

candle-power distribution is greatly altered by such change of shape. In order to have a way to estimate the total light flux and so properly understand such matters as the efficiency of a light, or to compare with each other lamps whose filaments are differently shaped, it is common to speak of their mean spherical candle-power. The mean spherical candle-power of a lamp is the average candle-power of the light source when viewed from all possible directions. This average is bound to be the same (in lamps of the same candle-power rating) regardless of the shape which the filament has been given. It is impossible to determine this mean spherical candle-power except by experimental measurements, and it is impossible to make measurements from all possible directions. As long ago as 1885 a number of selected directions for measurements around any lamp were chosen by a committee of the Franklin Institute and the method of determining the mean spherical candle-power then derived is still a good one to use in explaining it or in laboratory measurements, if better and quicker methods are not available. On a spherical surface 38 points may be selected at practically equal intervals around the light source, and through them measurements of candle-power are made of a light situated at the center. Latitude and longitude for them are:

On the equator every 30° from zero—12 readings

On meridian 0°—latitude 30° and 60° and 90°, then on around 120°, 150°, 210°, 240°, 270°, 300°, and 330°—10 readings.

On meridian 45°—latitude 30°, then 150°, 210°, 330°—4 readings

On meridian 90°—same as 0° omitting 90° and 270°—8 readings

On meridian 135°—same as 45°—4 readings.

In figure 4 a number of these points are seen on the sphere at the left. Their distribution is thus better shown than by the table.

Another plan much used for determining mean spherical candle-power makes direct use of the candle-power distribution curve and the fact that the candle-power of a source is really determined by the flux which proceeds from it. Suppose a source

giving uniform light flux in all directions, at the center of a spherical surface which is divided into equal zones. The amount of light flux through each zone would be the same. If an ordinary source of light with non-uniform light flux, and so with the candle-power varying from one direction to another, were then substituted, the flux would be different through each zone; but if the total flux from it were the same as from the light first mentioned, the average flux from all the zones would be the same as that previously found passing through any one of them. Since candle-power is determined by flux through a given area, instead

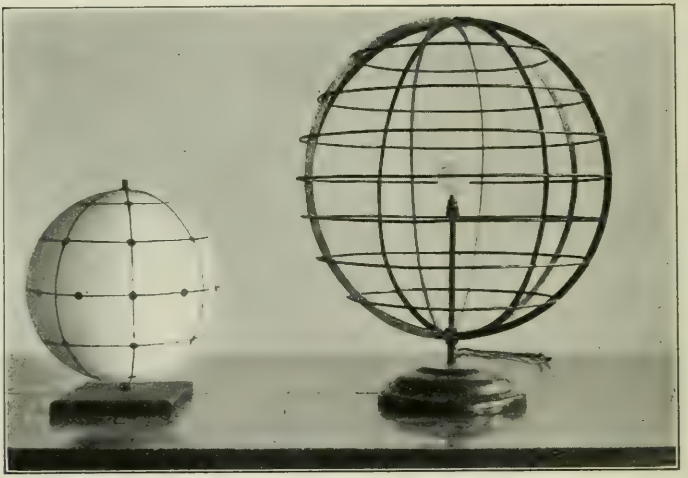


Fig. 4.—Models to aid in giving definite ideas regarding mean spherical candle-power and light flux.

of averaging the flux for each zone the candle-power through each zone may be averaged, and a corresponding value determined—the mean spherical candle-power. The plan of procedure is described below, beginning with the method of laying off equal zones.

Figure 5 shows part of a spherical outline divided into equal zones by planes indicated by lines 2, 3, etc., to 10. These planes are drawn at equal distances (d) apart. A theorem of geometry proves that this method of construction is correct. In the case taken the spherical surface is divided into ten equal zones. A

dotted line is drawn at the center of each of these zones and a radial line is drawn to the intersection of the surface and the dotted line. Since the flux (and the candle-power) of any source is irregular, and this line is drawn at the *center* of each zone, candle-power values read at these angles may be averaged, and the mean spherical candle-power thus determined. The ten lines marked with Roman numerals have been redrawn in figure 3, all of them being dotted except those numbered III and

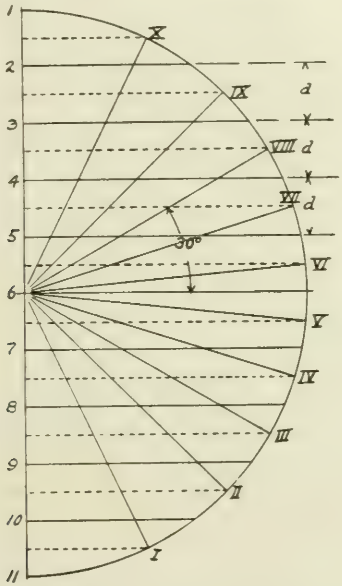


Fig. 5.—Method of dividing a spherical surface into equal zones

VIII, which come 30 degrees above and 30 degrees below the equator (horizontal line). In the case taken (curve *abcde*) readings along the radial lines marked with Roman numerals are

	C-p.		C.p.
I	13.6	VI	38.6
II	22.2	VII	37.8
III	28.2	VIII	34.0
IV	33.8	IX	25.8
V	37.1	X	11.7

Average 28.28
Mean spherical candle-power 28.28

In the hope that this may be made even more clear, reference

is made to fig. 4, in which at the right a spherical outline is shown divided by planes through the horizontal wires so there are four equal spherical zones above and four below the equator. The vertical candle-power distribution curve is an average of all possible vertical curves. In practical work it is customary to use ten zones above, and ten below the equator; the twenty candle-power readings obtained along lines drawn to the middle of each zone are averaged for the mean spherical candle-power. Flux polar paper having the proper dotted lines printed on it can easily be purchased.

Lamps of a given sort,—ordinary tungsten, inverted gas mantles, etc.,—all have such characteristics that the candle-power distribution about one is very closely duplicated by any other of the same type. Hence, once the mean spherical candle-power of one is determined and its ratio to some value like the mean horizontal candle-power (which it easy to measure) known, the mean spherical candle-power of any such lamp can be calculated. This factor, mean spherical candle-power/mean horizontal candle-power, is called the spherical reduction factor. Examples are:

Lamp	Mean horizontal candle power	Spherical reduction factor	Mean spherical candle power
Single horseshoe carbon........	16	0.81	12.96
Ordinary double loop carbon....	16	0.825	13.2
Stereopticon carbon............	50	0.892	44.6
Tungsten	48	0.78	37.44
Tantalum	20	0.79	15.8

Referring to the mean spherical candle-power determined from the curve of figure 3, the spherical reduction factor is found to be $28.28/38.1=0.74$. This is not in agreement with 0.78 of the table because the lamp considered is bowl frosted and not clear.

As the last matter to be included in this talk another term—light flux—should be defined. I have roughly defined candle-power. Imagine a light source at a point, giving 1 candle-power in all directions, enveloped by a spherical surface 1 foot in radius. All the light flux from the source passes through the spherical surface in divergent rays, the light flux per unit area being everywhere the same. (See figure 4.) If now on this surface any-

where, an area of one square foot is selected, the light flux through it is one lumen. Since there are 12.57 square feet on the surface ($4\pi r^2$), there are 12.57 lumens proceeding from the light source. The mean spherical candle-power multiplied by 12.57 will give the lumens from the source and will give it in any case. By placing an opaque surface over our spherical outline (see figure 6) and allowing light flux to proceed through an opening which represents 1 square foot of the spherical surface cut away, there may be seen by a divergent beam illuminated by

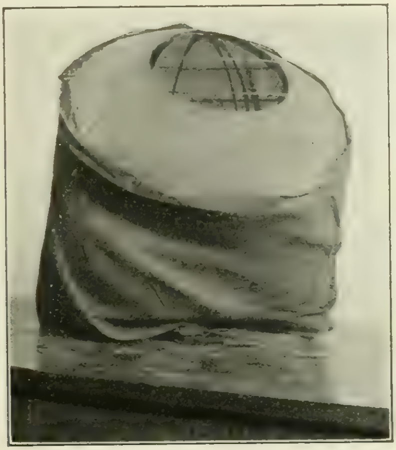


Fig. 6.—Model to represent one lumen of light flux.

dust particles, one lumen of light flux; a light of one candle-power being the source at the center of the sphere.

3. SHADES AND REDISTRIBUTION OF LIGHT.

The direction in which light flux is delivered by many sources makes them poorly adapted to practical uses. Sometimes a source is so small and bright that it is unpleasant and undesirable. In order to correct the natural candle-power distribution to something more desirable, to cut light flux off from some directions or to screen a very bright source from those who use its light, requires the application of some simple principles relating to intercepting and redirecting light flux. It is intended to first show these and then some of their applications.

Light flux passing from a source in a direction where it is not desired may be cut off by a shade. Any opaque object will do as the shade, for although light is a form of energy, stopping it off and absorbing it will cause no appreciable rise in temperature. The use and the possibilities of a shade are too simple and

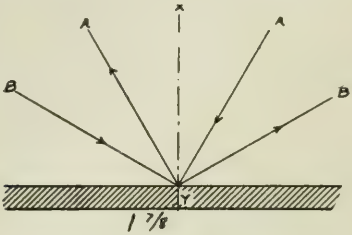


Fig. 7.—Regular reflection.

obvious to need discussion. It is much better, however, not to absorb the flux, but to turn it back and direct it to some point or points where it will be really useful. In doing this the principles of reflection are applied.

There are several sorts of reflection. The simplest is regular reflection, such as occurs when a beam of light flux strikes a polished metal surface or a glass mirror. (See fig. 7.) Such light flux is always turned back (reflected) so that the angle of

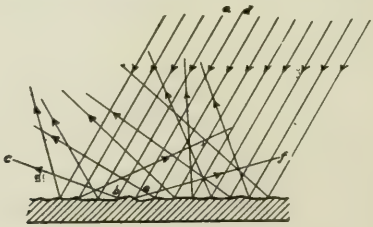


Fig. 8.—Diffuse reflection.

reflection is equal to the angle of incidence. A light ray coming from A at an angle of 30 degrees with a line *xy* perpendicular to the surface, is turned at the surface to A′ at an angle of 30 degrees with the perpendicular. Or B (at 60 degrees) is turned off to B′ at 60 degrees. Regular reflection occurs from every polished surface, even from that of clear glass (as may often be seen by looking into a window when it is not too bright

on the other side and noting objects reflected there). Another sort is diffuse reflection, which occurs when a beam of light flux strikes a surface which is not smooth and polished. Diffuse reflection occurs from any depolished surface. Fig. 8 shows how this is. The light rays are reflected from the minute irregularities according to the laws of regular reflection, but since each one is sent in a different direction, the light flux is spread all

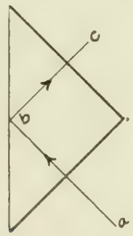


Fig 9.—Total reflection in clear glass.

about. It is rather remarkable to notice how little irregularity is necessary to secure diffuse rather than regular reflection. In fig. 5 the light along *ab* is turned to *bc* while that along *de* is turned so far away as to pass in the direction *ef* and the irregularity is not great. A mirror is such because it produces regular reflection over all its surface. Everyone knows how very smooth

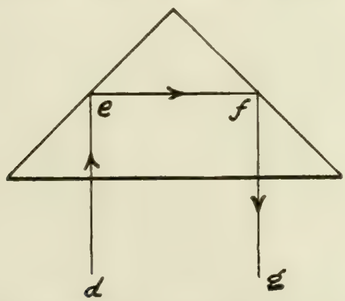


Fig. 10.—Total reflection at two surfaces of a clear glass prism.

a piece of metal must be before it has a mirror surface; that is, produces regular reflection. A third sort of reflection is total reflection, which occurs in a transparent medium,—glass being the one of most interest,—provided light strikes a boundary plane at a proper angle. Figs. 9 and 10 give examples. In each

case glass prisms are shown. In fig. 9 the light from *a* entering the surface perpendicular to it and so without reflection, reaches the transparent surface at *b* whence it is totally reflected (according to the law of regular reflection) and emerges toward *c*. When this is done experimentally and the prism is viewed from beyond *b*, looking toward *a* no light at all can be seen. In fig. 10 an arrangement is shown which results in total reflection occurring twice: at *e* and again at *f*. Total reflection does not occur unless the angle between the light ray in the glass and a perpendicular to the boundary surface between glass and air is about 45 degrees or larger.

When light is to be redistributed, it may be passed through a

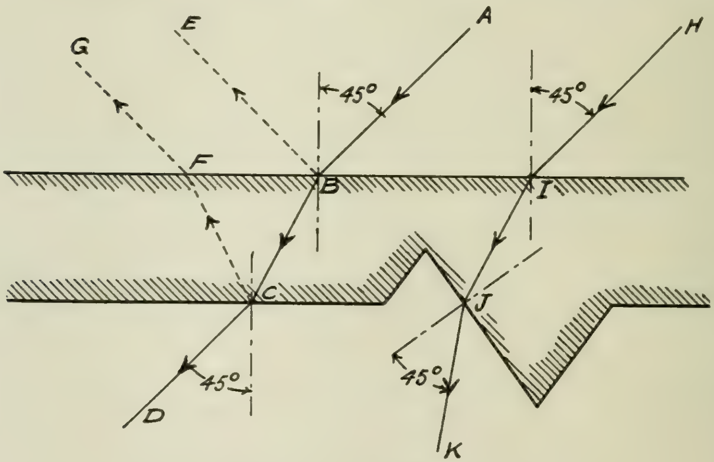


Fig. 11.—Refraction as light passes through glass.

suitable medium and there bent into desired directions. One way to bend it is by using refraction. A beam of light flux passing from a rarer to a denser medium (air to glass, for example) at an angle with the boundary surface between the media, is bent toward a line perpendicular to the surface. The amount of this bending varies with the properties of the media. Thus in fig. 11 the light ray AB striking the glass surface is bent into the direction BC and emerging is bent again into the direction CD. Or the light ray HI is bent into the path IJ and then to JK because of the arrangement of glass sur-

faces to produce this result. It may be noted that the refraction is always accompanied by some reflection from the surfaces of the denser medium. In fig. 11 the dotted lines show the paths of light reflected from the two glass surfaces. Only a small part is thus reflected, but enough to see clearly in suitably arranged simple experimental apparatus. Another way to bend light flux from its direct route is by making use of diffusion. When light passes through objects which are semi-transparent or in which particles have been placed to receive and redirect the flux, it is spread or diffused.

When light passes into or through media, there is always some absorption; some of its energy is spent and the light is fainter after it has passed through. The absorption in clear glass is noticeable, while in many sorts of glass which are semi-transparent or frosted, the absorption is enormous. This can readily be seen by interposing the medium whose absorption is to be observed, in the path of the beam from a stereopticon lantern. One must be careful, however, to make proper allowance for refraction or diffusion in such trials. Tables of absorption for many materials may be found in handbooks. Colored glass absorbs all the light except that of the particular color transmitted.

The application of some of these principles in a practical way may be studied by simple apparatus. With a plane mirror and a light source, the effect of regular reflection may be observed by the aid of dusty air in which also the beam of redirected light which is secured may be noted. Substitute a metal surface painted with aluminum paint or a white cardboard surface and the reflected beam is lost. If one looks at the surface, however, the appearance is quite different from that of the mirror. No light could be seen on the mirror except from one direction. Light comes to the observer from the other surfaces no matter where he stands. While it is not always easy to tell how much light comes from a surface by looking at it, one can tell in what direction the light is coming by making observations, and this method should always be used in examining reflecting and refracting surfaces, and estimating their value.

Reflectors around single lamps commonly have a conical form.

Taking a 90 degree mirror cone reflector one may examine some of its properties by using a coiled filament stereopticon incandescent lamp mounted on a rod so it can be moved within the cone as desired. If the light source be placed at the center of the plane of the open end, all light is cut off above this plane; while the light which is reflected is turned back so that the light is concentrated. If the light is moved up into the cone, light flux is cut off from a larger spherical angle, while the emerging light is a little less concentrated. This and much besides is nicely stated in a paper by Dr. Bell in the TRANSACTIONS of the Illuminating Engineering Society, November, 1909, "Principles of Shades and Reflectors." Turning the reflector so an observer may look into it, the regular reflection shows by the source itself becoming visible in the mirror surface. It is only from such place or places that light comes to him. As the source is thrust further into the shade, the light spots in the reflector gather together.

Now substitute for the mirror shade one with a surface which gives diffuse reflection, and quite different results are secured. Direct light is cut off as before, but the reflected light comes from all parts of the shade and spreads all about. In fact, in using diffuse reflection the angle of the shade is of no consequence except as it may be of value as a means of cutting off direct light from the source. The amount of light sent in any direction depends on the area of the lighted surface which can be seen from there.

Intermediate results between regular and diffuse reflection may be secured by using surfaces partly reflecting and partly diffusing, shaped to give regular reflection, while the diffusion is enough to take away the unpleasantness of sharply defined light rays.

Diffusion is much used in order to improve light distribution. The frosting of a lamp is an example. Diffusion makes it impossible to see the bright source itself and spreads the light so that the flux is independent of the original candle-power distribution. The frosted surface becomes a secondary source at reduced brightness. Diffusion may be also secured by the use of opal glass or any other medium which has the requisite properties.

Often diffusion is secured at quite too great a cost in absorption. Hence, diffusion by refraction is particularly nice since it causes so little loss of light.

Total reflection of light in a transparent medium is also an important means of redirecting light. By placing the source at a proper location and shaping glass surfaces to produce total reflection, remarkable results in redistribution can be accomplished. The fundamental principle is simple. The practical application requires much care in design and accuracy in workmanship. The work done in this line by makers of prismatic glassware is fairly well known. Sometimes prisms on the inside of shades are designed to produce refraction and so spread the light to cover the shade, while on the outside refraction and total reflection are both used to secure the proper direction of flux distribution. The effects can best be seen by placing a concentrating shade over an incandescent lamp and noting the change in light distribution. Upon looking into the shade one may observe where the light comes from. Diffusion by refraction and redirection by total reflection may be combined to assist each other in making a shade which redirects light, diffuses it, and at the same time absorbs but little.

The redistribution of light by shades may produce striking alterations in the candle-power distribution curve. A vertical candle-power distribution curve for an alba glass shade is plotted on fig. 3 in curve *fghij*, using these measured values:

Deg.	C-p.	Deg.	C-p.
0	40.5	100	19.6
10	44.6	110	22.0
20	42.0	120	22.3
30	35.2	130	22.7
40	37.0	140	22.2
50	34 4	150	21.3
60	26.8	160	20.0
70	20.0	170	16.5
80	16.8	180	0.0
90	17.8		

The redistribution is manifest. The horizontal candle-power has been cut down from 38.1 candle-power to 17.8 candle-power (see curve) while the candle-power out of the end has been increased from 10 to 40.5 or to four times as much.

It may be noticed that between 140 degrees and 180 degrees more light flux passes out than would have passed in that direction from the bare lamp since the candle-power values there are higher. For most purposes this would be a fault; but it is probably a sacrifice which has to be made in order to gain advantages which have been secured elsewhere.

The mean spherical candle-power of lamp with a shade may be determined by taking readings from curve *fghij* along the lines marked with Roman numerals, as follows:

	C-p.		C-p.
I	37.4	VI	18.8
II	36.3	VII	21.7
III	27.0	VIII	22.5
IV	19.0	IX	22.6
V	17.3	X	20.9

Average 24.35
Mean spherical candle-power 24.35

The efficiency of the shade may be determined from data now at hand, for the mean spherical candle-power has been determined both without and with the shade. Taking these values, the

$$\text{Efficiency of the shade} = \frac{\text{m.s.c.p. with shade}}{\text{m.s.c.p. without shade}} = \frac{24.35}{28.28} =$$

86.1 per cent. Even if this efficiency should be only moderate, the advantage of having properly directed light might well warrant the use of the shade. Efficiencies of 90 per cent. can be reached with well designed modern shades.

4. CALCULATION OF ILLUMINATION.

In a former talk the unit of light flux (the lumen) was defined by considering the whole flux passing through a sphere placed concentrically around a light source. If the sphere has a radius of 1 foot, the light is 1 candle-power in all directions, and one considers an area of any shape, anywhere on the spherical surface the surface of this area being 1 square foot, the flux passing through this is 1 lumen. (This is shown in fig. 6.)

If another enveloping spherical surface having a 2 foot radius is put around the first one, the same flux which passed through the 1 square foot area will there be spread over 4 square feet, for the whole surface is 4 times as much and the same total flux

spreads uniformly over every part of it. The surface of the first is $4\pi \times r^2 = 4\pi \times 1^2 = 12.56$ square feet, while that of the enveloping one is $4\pi \times 2^2 = 12.56 \times 4 = 50.24$ square feet.

The illumination of a surface depends on the light flux which strikes it. If a surface on the outer developing sphere is illuminated to a value equal to that already noted on the inner one, the light flux would have to be 4 times as great or the source have 4 candle-power. Unit illumination is that produced on the surface of the inner sphere when a 1 candle-power source is at its center or on the outer sphere when a 4 candle-power source is at its center

The unit of illumination is the foot-candle. With a uniform 1 candle-power source at the center of a sphere having 1 foot radius, every point of the inner surface of the sphere is illuminated to 1 foot-candle. One lumen on each square foot produced 1 foot candle. With a 4 candle-power source it would be illuminated to 4 foot-candles. If the source has 4 mean spherical candle-power but an irregular distribution, the illumination is irregular and at any point is proportional to the candle-power in that direction.

On the surface of the enveloping sphere having a radius of 2 feet, the illumination will be ¼ foot-candle with a 1 candle-power source, or 1 foot-candle with a 4 candle-power source. At doubled distance, then, the illumination is only ¼ as much; or, in short, illumination (foot-candles) = distance in feet²/candle-power. This is the inverse square law which has great importance in illumination and in light measurements.

Using a source arranged to produce a cone of light on a surface, one can see experimentally that doubling the distance of the source from the screen quadruples the area to be covered and that the illumination diminishes a great deal. If the area is 4 times as great, the illumination due to the same flux *must* be only quarter as much. It should be noted, however, that the illumination produced on a flat screen in such an experiment cannot be uniform, since the distance from the source to every part of the screen is not the same. Furthermore, knowing the candle-power of the lamp in use and its distance from the surface illuminated, one can calculate the illumination only on a plane perpendicular

to the incident ray at the distance of the plane along this perpendicular.

It is well to note also that for all sources this inverse square law does not hold true. Using a parallel light beam due to a parabolic mirror or a concentrating shade, such as might be used with a headlight or a searchlight, the illumination is not noticeably different on surfaces at greatly different distances. The area covered by the light beam is the same at any distance.

A principle has already been announced of great use in calculating illumination: the bigger the area lighted by a source, the lower is its illumination. This same principle holds if the surface to be lighted is inclined to the light rays, as may readily be shown by turning a screen originally perpendicular to the source lighting it. Fig. 12 shows a magnified light ray from L at a height h above a plane striking it obliquely.

The surface $abcd$ = S $\qquad$ $abfe$ = S′

Illumination on S : Illumination on S′ = S′ : S

$$\text{Illumination on S} = \frac{\text{C-p.}}{r^2}\ ;\ \text{and S}' : \text{S} = ad : ae = r : h$$

$$\text{Therefore, } \frac{\text{C-p.}}{r^2} : \text{illumination on S}' = r : h$$

$$\text{Illumination on S}' \times r = \frac{\text{C-p.}}{r^2} \times h$$

$$\text{Illumination on S}' = \frac{\text{C-p.}}{r^3} \times h.$$

The latter equation is used for calculations made further on. Continuing:

$$\text{Illumination on S}' = \text{c-p.} \times \frac{h}{r^3} = \text{c-p.} \times \frac{h}{r^3} \times \frac{h^2}{h^2} = \frac{\text{C-p.}}{h^2} \times \frac{h^3}{r^3} = \frac{\text{C-p.}}{h^2} \cos^3 a.$$

Tables of $cos^3 a$ are found in some books. Usually calculations of illumination are made by substitution of candle-power values in the direction desired (angle a) dividing by the square of the height of the source above the plane (h) and multiplying by the factor ($cos^3 a$).

In fig. 13 there is shown a 40-watt tungsten lamp in a prismatic focusing reflector 6 feet above a plane to be lighted. The candle-

power distribution curve for the lamp is plotted and since the

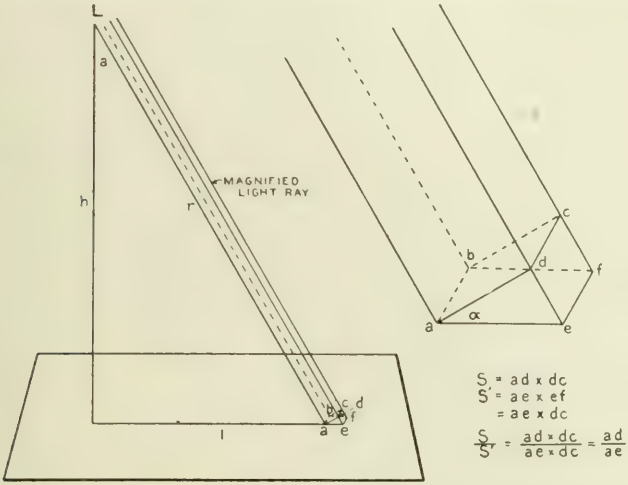
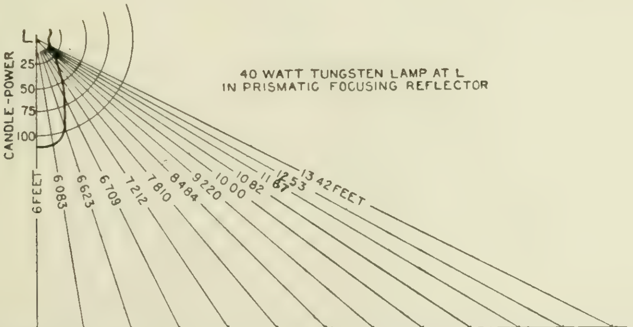


Fig. 12.—Representation of light flux striking a plane obliquely to it.

drawing is made to scale, the oblique distances of the light ray to reach the plane to be lighted at 1, 2, 3, etc., feet out from the



FEET ALONG A HORIZONTAL PLANE	0	1	2	3	4	5	6	7	8	9	10	11	12
FOOT-CANDLES DUE TO A 1 C-P SOURCE	028	027	024	020	016	012	.010	.0076	.0060	.0047	0038	0030	.0025
CANDLE-POWER DUE TO LAMP L	112 7	111 8	960	644	444	39.7	285	26.1	21 7	190	189	164	161
FOOT-CANDLES DUE TO LAMP AT L	313	2 98	2 28	1 28	71	.50	28	20	13	09	07	.05	04

Fig. 13.—Tabulation of candle-power and illumination from a source on a plane six feet below it.

base of a perpendicular dropped from the lamp are shown and marked. In the table below the foot-candles due to a source

giving one candle-power in all directions are given for each such point. They are calculated thus:

$$\text{Illumination on } S' = \frac{\text{C-p.}}{r^3} \times h$$

substituting for a point 2 feet away.

$$\text{Illumination} = \frac{1}{6.623^3} \times 6 = 0.024 \text{ foot-candles}$$

substituting for a point 8 feet away.

$$\text{Illumination} = \frac{1}{10.0^3} \times 6 = 0.006 \text{ foot-candles.}$$

The next line gives candle-power due to lamp L and these are readings from the candle-power curve as may readily be seen. The last line may be directly calculated thus:

Substituting for a point 2 feet away

$$\text{Illumination} = \frac{96.0}{6.623^3} \times 6 = 2.28 \text{ foot-candles.}$$

substituting for a point 8 feet away

$$\text{Illumination} = \frac{21.7}{10.0^3} \times 6 = 0.13 \text{ foot-candles.}$$

or the values due to a 1 candle-power source may simply be multiplied by the candle-power of the lamp under consideration in the direction considered. Thus

for a point 2 feet away

$$0.024 \times 96 = 2.28 \text{ foot candles}$$

for a point 8 feet away

$$0.006 \times 21.7 = 0.13 \text{ foot-candles.}$$

It will be observed that with doubled distance from the source (6 feet and 12 feet) how the illumination diminished to much less than ¼ the former amount, because of obliquity of the surface (read on the line showing illumination due to a one candle-power source).

When a calculation is to be made for an actual room, all the sources must be considered at once—for example, 2 lamps, such as have been considered, on vertical axes placed in a room 8 feet

6 inches from floor. Fig. 14 shows the lamps in position. The illumination plane is 2 feet 6 inches above the floor, a common table height. In the figure the first and second horizontal rows of figures are copied from the values deduced and recorded on fig. 13; the third line gives the sum of the values above, for the illumination at each point is the summed up value of those separately produced by each source at that point. The curve of illumination at the bottom of the figure is plotted from the values recorded above it. It will be noted that the highest illumination is not directly below the lamps and that it diminishes rapidly

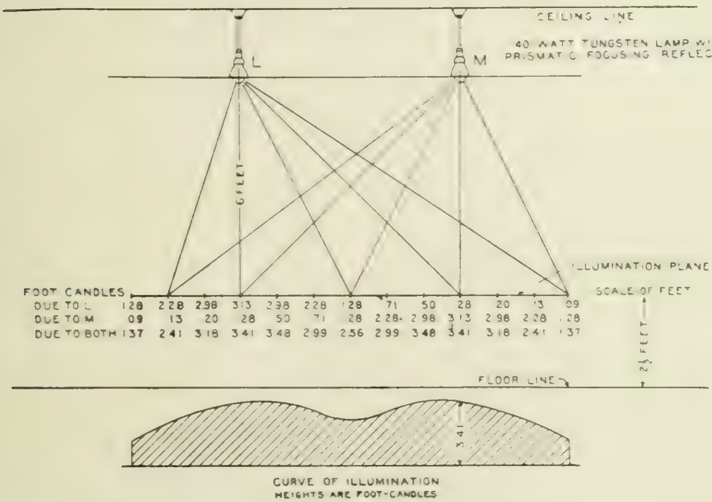


Fig. 14.—Diagram and data to show illumination due to two sources lighting the same surface.

near the ends of the room. The calculations are made for direct illumination, no account being taken of light reflected from surroundings. Sometimes this reflected light is very important; sometimes it does not count for much.

The amount of illumination to use in various interiors varies considerably. I shall not attempt to prescribe what it should be, since it is out of the province of this paper and it is a matter of personal judgment in most cases. I have seen such curious recommendations as that a school room be illuminated to 1.25

foot-candles, while a drawing room should have from 5 to 10 foot-candles.[1]

A consideration of the calculation of illumination would be incomplete unless the practical problem of finding what lamps should be used to produce a given or desired illumination. To secure an illumination of 3 foot-candles, there must be 3 lumens on each square foot of the area to be lighted. Hence multiplying the number of square feet of area to be lighted by the illumination in foot-candles desired gives the total lumens required from the light sources to be used. The light sources used must produce more than the total lumens which have been calculated, in order to allow for losses. Such allowance may be made by using a multiplying *factor* to get the lumens to be supplied by the lamps. (*A factor of 2* will be about right in ordinary practise to allow for efficiency of shades, waste light, etc.) Knowing the lumens given by each lamp (this information may be had from lamp manufacturers catalogs) one can determine the size and number of lamps to be used.

Light source	Lumens	Consumption. Cu. ft.	Lumens per cu. ft. or per watt	Ave.
Reflex gas burner (2.5″ press)	725	3.31	219	250
Welsbach Junior " "	435	1.66	262	
Intensive upright mantle (2.5″ press.)	1210	5.12	236	
Ordinary fish tail (gas) " "	360	7.23	50	50
		Watts		
Tungsten (110–125 v.)	320	40	8.0	8
" "	830	100	8.3	
" "	1670	250	6.7	
Gem "	160	40	4.0	4
" "	335	80	4.2	

A room 20 feet × 100 feet has 2,000 square feet of surface.

[1] In order to show what 1, 2, 3, 4, foot-candles of illumination look like, an exhibition was made of compartments constructed and placed side by side, so that the light from one could not reach the others, but all could be viewed at once by an observer who could not see the lamps furnishing the light. The light flux was received on newspapers. In this apparatus 20-c-p. lamps were used. The distance, one of them should be placed from a screen, or plane of use, to secure 1 foot-candle of illumination, may be determined thus: We have

$$1 = 20\,d^2 \qquad d = \sqrt{20} = 4.47 \text{ ft.}$$

Then for 2 foot-candles, 2 lamps may be used; for 3 foot-candles, 3 lamps, etc. With this model before the audience, notice was taken of how a change in color of the surface illuminated affects the result, by interposing white cardboard, black cloth, etc., over the newspaper screen which had been in place.

In another experiment the relation of light position to amount of satisfactory illumination was shown. A 500-watt tungsten lamp directly before the faces of the audience was used to light a screen to four foot-candles, and the result compared with that secured when the lamp was covered but the screen given the same illumination.

If illuminated to three foot-candles, $2{,}000 \times 3 = 6{,}000$ lumens on the illumination plane are required. For this $6{,}000 \times 2 = 12{,}000$ lumens at the lamps are needed and the number of lamps are selected from the above table.

Since the lumens per cubic foot or lumens per watt are moderately constant for a given sort of lamp, a certain number of cubic feet of gas per square foot lighted or watts of electrical energy must be required for a definite illumination. This may be determined as follows:

For Welsbach lamps $\frac{250}{2}$ lumens per cu. ft. is useful. Hence, for 1 foot-candle (1 lumen per sq. ft.), $\frac{1}{125} = 0.008$ cu. ft. of gas per sq. ft. of area.

For tungsten lamps $\frac{8}{2}$ lumens per watt is useful. Hence, for 1 foot-candle (1 lumen per sq. ft), $\frac{1}{4} = 0.25$ watts per. sq. ft. are required.

Such a table as the following results:

For foot-candles	Gas mantle lamps cu. ft. per sq. ft.	Tungsten lamps watts per sq. ft.	Gem incandescent lamps watts per sq. ft.
1	0.008	0.25	0.50
2	0.016	0.50	1.00
3	0.024	0.75	1.50
4	0.032	1.00	2.00
5	0.040	1.25	2.50

A room which is lighted by electric lights and does not give near 4 foot-candles for 1 watt per square foot has dark walls, globes which cut off much light and direct it improperly, or both.

5. PHOTOMETRY.

Perhaps a better topic would have been "Measuring Light," for it is my intention to show that light measurements are not difficult involved things requiring special apparatus. Difficulty and complexity arise when the aim is to secure high accuracy, to suppress troublesome variables, and the like.

At first it should be noted that it is impossible to judge the amount of light coming from a source by looking at it. It may be that one gets an impression of a large amount of light or a

small one, but nothing more than this, unless he knows something of the particular lamp in view which betrays its candle-power. For example, no one who knows arc lights would estimate the candle-power of any of them at less than a couple of hundred. On the other hand, he might estimate one which gave 200 candle-power at 2,000 candle-power, merely because his recollection of data seen somewhere persuaded him to this. It is easy to vary conditions under which lights are operated so that one's judgment can be entirely set at fault. For example, a small incandescent filament in a large bulb or a carbon filament in an ordinary lamp burned as white as a tungsten filament would make it impossible to formulate even a crude idea of what was the candle-power of the source.

The light given by a source must be measured by the illumination it produces. In showing how this is done in practise, a few simple principles will be made use of, which can be applied without special apparatus.

1. *The Rumford Principle.*—The apparatus required to compare the light of two lamps is a small rod which casts its shadow against a light background. If one takes such a piece of apparatus and sets two lamps so that shadows cast by each of them are of equal density, simple measurement of the distance of the lamps will give the data necessary to determine their relative candle-power; for the fact that the shadows have equal density shows that the illumination on the screen produced by one light is the same as that produced by the other. In the shadows the illumination is due to one lamp only. The principle behind the method of getting a result may be shown by the following derivation:

$$\text{Illumination by A} = \frac{\text{C-p. of A}}{(\text{distance of A})^2}.$$

$$\text{Illumination by B} = \frac{\text{C-p. of B}}{(\text{distance of B})^2},$$

if illumination by A = illumination by B,

$$\frac{\text{C-p. of A}}{(\text{distance of A})^2} = \frac{\text{C-p. of B}}{(\text{distance of B})^2},$$

or

$$\text{C-p. of A} = \frac{(\text{distance of A})^2}{(\text{distance of B})^2} \times \text{c-p. of B}.$$

In fig. 15 such an apparatus is shown. A rod (R) is casting two shadows on a white cardboard screen. The right hand shadow is cast by the left hand light; the same shadowed place is lighted by the right hand lamp only. Hence when the illumination of the right hand shadow (by right hand lamp) is the same as that of the left hand shadow (by left hand lamp), the formula above may apply; and if the horizontal candle-power of one is known, the other is determined, distances being from either lamp to the space lighted by it alone. In the figure the left hand lamp must be moved further away or the right hand one be moved up to secure equality of illumination.

It is possible to arrange simple apparatus so that in place of

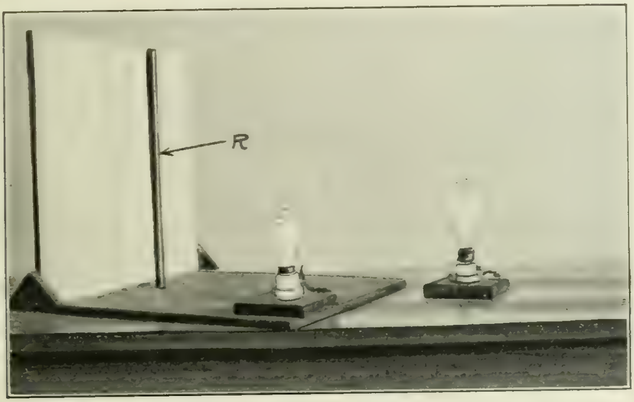


Fig. 15.—The principle of the Rumford photometer.

having two shadows cast, the two lights to be compared send their light flux through an opening in an opaque board at such an inclination that the light which each of them casts is received on a screen, appearing as two spots side by side. By matching the illumination of these two spots, a comparison is easily made.

2. *The Ritchie Wedge.*—If a sheet of white cardboard is doubled so that its two parts form 90 degrees with one another, and this is placed between two lights in the line connecting them, so that the inclined surfaces are both viewed by an observer, one of them being illuminated from one light and the other from the other, it is easy to find a place between the lights at which the illumination due to the two lights is the same. When this is

done, the distances of the lights from the screen can be made a basis of comparison.

In figure 16 such an apparatus is shown. It is quite clear that the right hand lamp is producing an illumination on the right hand surface of the wedge far greater than that produced by the lamp at the left.[2] To secure "a balance," therefore, the lamp at the right must be moved further away. When the illumination is the same, the formula already stated will apply. Thus, suppose, when a balance has been obtained, the distance of the left hand lamp from the screen is 3 feet while the right hand lamp is at 5 feet distance. Then if the candle-power of the left

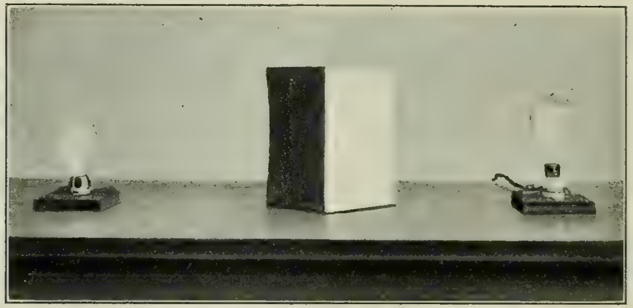


Fig. 16.—The principle of the Ritchie photometer.

hand lamp (B) is known to be 20, that of the right hand (A) is

$$\text{C-p. of A} = \frac{5^2}{3^2} \times 20 = \frac{25}{9} \times 20 = 55.5 + \text{c-p.}$$

3. *The Bunsen Spot or Grease Spot Device.*—If a sheet of paper on which there is a spot of grease is viewed by reflected light, the spot is dark and its surroundings white, because the spot is more transparent than its surroundings, and a fairly large pro-

[2] At the talk a comparison between an upright Welsbach mantle light and a reflex mantle light equipped with a reflector was made. The comparison was between the horizontal candle-power of the upright light and the vertical candle-power of the reflex burner with its shade. Directly below the reflex burner a mirror was placed at 45 deg., in order to turn the vertical light flux in a horizontal direction opposite the flux coming horizontally from the upright mantle. The wedge was moved to a place where the illumination was balanced or equal, and then the distance measured on the one hand to an upright mantle, and on the other side to the reflex mantle by way of the mirror. The relative candle power was then calculated in the same way as in the last illustration, but an allowance is made for the reflecting coefficient of the mirror, taking this at 80 per cent.

portion of the light passes through it. On the other hand and for the same reason, if viewed by transmitted light, the spot is light and its surroundings dark. It will then be necessarily true that if a paper showing a grease spot is placed in a position between lights as shown in fig. 17, with the plane of the paper perpendicular to the line connecting the lights, it can be moved to a location where the spot will disappear, because the amount of reflected and transmitted light would then become equal. This can be true only when equal illumination,—that is, equal light flux per unit area,—is received on each side of the paper. Using such a grease spot, a comparison of lights can easily be made.

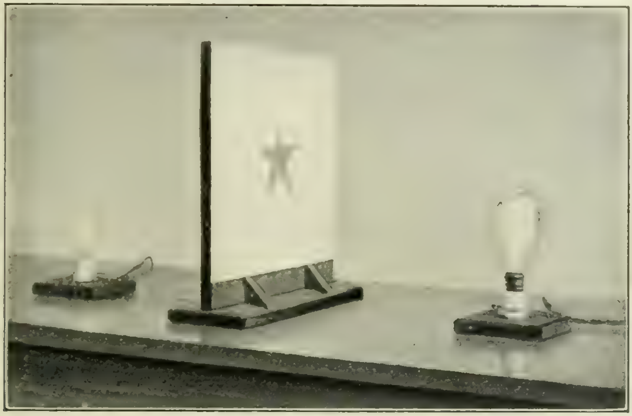


Fig. 17.—The principle of the Bunsen photometer.

This particular apparatus or some modification of it is more used than any other for photometric measurements.

In the figures the fact that the grease spot shows dark is an indication that the amount of light transmitted from the left hand lamp is less than that received on the screen from the right hand lamp. Hence, the right hand lamp must be withdrawn from the screen or the screen moved nearer the left hand lamp in order to cause the grease spot to disappear.

4. A very small piece of apparatus applicable especially to comparison work where only approximate results are desired and where some very small portable apparatus is valuable is found in a small block of paraffin,—originated by Mr. W.

D'A. Ryan, of the General Electric Company, a number of years ago. This consists of a rectangular block of paraffin about three inches long and about three-quarters of an inch in cross-section. Through the center of the block dividing it into two equal rectangular parts three-eights inch by one inch (3 inches long) runs a dividing plane of bright tinfoil. The back. top, and bottom of the block are also similarly covered. Now if this little block be held by an observer in a path between two light sources with long axis vertical, that side of the block from which a greater amount of light flux comes will appear bright; the other side will seem dark. It is not hard to move to a location where equal illumination is received on both sides, and then a calculation of the relative candle-power of the two sources can be computed from data such as the following. Two arc lamps are on poles 190 feet apart. Holding the block up before him the observer goes to a point 120 feet from A and 70 feet from B. Here he decides both halves of the block are equally lighted. Hence

$$\frac{\text{C-p. of A}}{\text{C-p. of B}} = \frac{120^2}{70^2},$$

$$= \frac{14,400}{4,900},$$

$$= 2.94.$$

A therefore 2.94 times are many candle-power as B.

In order that there be no misunderstanding, it may be well to repeat in closing that the attempt above is simply to show the fundamental principles of photometry. There are a good number of places in which this apparatus would be right to use for comparisons. However, the refinements used in constructing laboratory photometers are very necessary and many things not even referred to above must be taken account of if *accuracy* is to be obtained.

Another thing of great importance is the standard of reference for candle-power. What shall it be and what accuracy has it? This paper will not attempt any answer.

REPORT OF THE COMMITTEE ON ILLUMINATION PRIMER.

To the Council of the Illuminating Engineering Society:

The committee on illumination primer was appointed October 13, 1911, and requested to prepare "an elementary discussion of the principles of good illumination, including, of course, only such points or principles which are established beyond peradventure, and which the society can endorse."

At the meeting of the council, held November 10, the committee asked for more specific instructions as to the plan and scope of the work. The sense of the council appeared to be about as follows:

(*a*) The illumination primer or discussion of the elementary principles of illumination, is intended primarily to educate the *public* in the proper use of light.

(*b*) The material presented in the primer should be of the simplest character, readily understood by the layman. The use of technical terms should be avoided.

(*c*) In connection with the text, the use of photographs and diagrams illustrating proper and improper use of light is advocated.

(*d*) The primer should be as brief as possible: minimum length suggested, 8 pages,—the size of page in our TRANSACTIONS; maximum length suggested, 24 pages.

(*e*) The subject matter of the primer to be published in the TRANSACTIONS; thereafter authorized reprints to be published and widely distributed.

At the council meeting held January 12, 1912, the committee reported in part, as follows:

Following the conception of the task which you have set before your committee, we have in an advanced state of preparation, the manuscript of a brief primer on illumination. In doing this we have taken up the function of the eye and the general characteristics of vision, the requirements of illumination from the standpoint of ocular hygiene, the terms in which illumination is most simply reckoned and defined, the general requirements of illumination with respect to amount, color, and diffusion, the fundamental principles of placing light sources and shielding them, the rudimentary principles of shades and reflectors, the general properties

of commercial illuminants, the effect of the surroundings upon the illumination received, the avoidance of glare, and the elements of the placing and distribution of illuminating sources.

We have not attempted to enter into any discussion of photometry and minor technical differences between illuminants, of the formulae for the computation of illumination beyond the general effect of the distance of the source; nor have we in any manner attempted to discriminate between the various commercial sources of light, be they oil, gas or electric, all of which may be, and have been, successfully used for thoroughly good practical illumination. In other words, we have rigorously avoided technicalities except in so far as a mere glimpse at them is necessary to reinforce principles which we have set down.

We do not see our way clear, even with the modest program which we have set before ourselves, to keep the primer within less than twenty-five to thirty pages of approximately the size of our TRANSACTIONS. Even this length would necessarily be greatly exceeded if we were to enter upon the wide field of technical details.

At the council meeting held April 12, 1912, the committee reported in part, as follows:

Several drafts of the primer have been prepared, and after numerous revisions, a draft consisting of twenty-eight typewritten pages was submitted for criticism to fifteen persons who were taken to be representative of the average public for whom the primer is intended.

As a result of the criticisms received, the committee decided to revise, simplify and shorten the text, and a new draft has been practically completed.

At the council meeting held May 10, 1912, the committee reported in part, as follows:

At the present time the subject matter of the original drafts and the suggestions secured from many friends, have been boiled down to about five thousand words, which, with some twenty illustrations, the copy for which is now in hand, will make up a sum total of approximately twenty pages of our TRANSACTIONS.

The later revisions of the subject matter have not been extensive and have been in the direction of simplification and a more popular form of presentation.

In the present revision, which it is hoped will be the final one, your committee finds itself in somewhat of a quandary as to whether it more nearly accords with the intent of the society to issue a primer of about the present length, even if it comes to the point of being somewhat too didactic, or whether a still more popularized form of presentation should be adopted, and if necessary, with increased length over that already mentioned, of perhaps thirty to fifty per cent.

A large part of the work of the committee was carried on by correspondence, extending over a period of six months. The committee has held seven regular meetings this year as follows: January 11, 12, 13; February 9, 10; March 14, 15, 16, 17, 18, 29, 30; April 11, 12; May 9, 10; June 3. Besides these meetings a number of informal conferences and meetings were held with both technical and non-technical friends.

Numerous revisions of the manuscript were made from time to time to meet the situation, and the final manuscript submitted to the council at the meeting of June 14 is the fourteenth draft of the committee.

The committee has had the benefit of the advisory services of many of the members of the society, in criticisms of the preliminary drafts and photographs, suggestions for improvement, etc., and wishes to acknowledge its indebtedness to all of these,—too numerous to enumerate here.

It has also had most valuable suggestions and assistance from friends outside of the society, whose broad points of view have been particularly valuable in guiding the committee to meet the requirements of the public.

In the preparation of photographs for illustrating the text, the committee desires to acknowledge the courtesy and co-operation of the New York Edison Company, the Consolidated Gas Company of New York, the Edison Electric Illuminating Company of Boston, the Commonwealth Edison Company of Chicago, the United Gas Improvement Company, Philadelphia; and others, both companies and individuals.

The committee has aimed at the exposition of *principles*, be the source of light what it may, and believes that there is nothing in the text or illustrations of the primer to militate against its distribution by either gas or electric light companies.

In putting the manuscript for the primer into its final form, the committee has taken into consideration first of all, that the primer must be both untechnical and readable. To this end it has been necessary both to omit many matters which would receive proper consideration in a text-book, and to make many statements of fact without going into the technical considerations which lead to them. Any other policy than this would, in

the opinion of the committee, inevitably have led to the production of a treatise rather than a primer,—a treatise too, which would have been absolutely unreadable to the non-technical public whom it was our first duty to instruct and interest. For the same reason, we have departed widely from the systematic, pedagogical order which would be found in a college text-book, and have reverted to the less orderly, but more striking methods of presentation which educators have found best adapted to elementary instruction.

As a result, the primer has been brought down to a readable length,—about 3,500 words or approximately ten pages of our TRANSACTIONS. With the score of illustrations we have added, the total size of the pamphlet may reach twenty pages of our TRANSACTIONS,—the greatest space, in our opinion, that it is safe to take, even with a primer in which there are many illustrations,—if it is expected to be read by those whom it is chiefly to benefit.

With respect to the illustrations, the process of selection has proved to be a most difficult one. Those which have been incorporated in the primer were chosen from about 125 plates, nearly all specially taken for this work. It is an easy matter to get photographs suitable for illustrations before a technical audience, but it has proved superlatively difficult to obtain those so characteristic and unmistakable as to have a definite meaning to the general public. The captions for the illustrations have been prepared, not after the ordinary routine, but deliberately for instructional purposes, so that if a casual reader merely skimmed the text, he would still get something of distinct educational value from the pictures.

In pursuance of this same end,—of making the primer chiefly inspirational rather than didactic, the committee thought it wise to cover as many important phases of the subject as possible, even at the risk of doing so briefly and *ex cathedra*, rather than to reduce the pamphlet to readable size by covering fewer subjects at perhaps tiresome length.

Apart from the desirability of briefness for the sake of holding the attention of the audience, it was deemed inadvisable further to extend the primer, on account of the necessary and

considerable increase in cost. We believe that the end set before us by the society will best be met by producing a primer which can, without forbidding expense, be published not by hundreds or by thousands, but by hundreds of thousands.

The committee herewith submits the final draft of the primer, together with the illustrations.

Respectfully submitted,

COMMITTEE ON ILLUMINATION PRIMER,

(Signed) LOUIS BELL,
J. R. CRAVATH,
L. B. MARKS, *Chairman.*

SPECIAL REPORT OF COMMITTEE ON ILLUMINATION PRIMER.

COUNCIL MEETING, JUNE 14, 1912.

To the President of the Illuminating Engineering Society:

In response to your letter dated May 29, 1912, requesting our committee to submit recommendations as to method of utilizing the primer, we beg leave to submit the following suggestions:

First. The primer should be sent in regular course for pubilcation in the TRANSACTIONS in time for the Annual Convention.

Second. Plates should be prepared for the publication of the primer in form suitable for general distribution, with suitable type, title page and cover. In our opinion, the type and paper of the TRANSACTIONS is not suitable for the production of the pamphlet for general publication.

Third. An edition of not less than 5,000 copies should be printed for distribution to members of the Society, and other uses.

Fourth. We believe that provision should be made for further editions to be placed on sale at a figure just sufficient to suitably cover the expenses of production and distribution. We are not in favor of placing a price materially higher than cost, as thereby the wide distribution of the primer, which is the real reason for its production, would tend to be defeated.

Fifth. We recommend that permission be granted to responsible persons to reprint the primer for their own free distribution, provided that it is thus used entire, without interpolations.

Sixth. We further recommend that copies of the separately published primer with the price at which it is available for distribution, should be sent to the various societies, organizations, etc., which might be interested in utilizing it.

Seventh. We regard it as indispensable to the success of the general distribution of the primer that the pamphlet for this distribution should be in print by Aug. 1st, in order that the lighting companies and others interested in its prompt distribution at the commencement of the lighting season should be able to make timely preparation for ordering or reprinting it.

Respectfully submitted,

COMMITTEE ON ILLUMINATION PRIMER,

(Signed) LOUIS BELL,
J. R. CRAVATH,
L. B. MARKS, *Chairman.*

LIGHT: ITS USE AND MISUSE.*

It is the purpose of this publication to assist the user in making artificial light effective, whether the light be produced by oil, gas, electricity or otherwise.

By proper use you can get good illumination from any of these sources, but by misuse you are likely to get lighting that is bad, costly, and even dangerous to the eyesight.

ILLUMINATION AND COMFORTABLE VISION.

To see easily and comfortably you must select the lamps, fix-

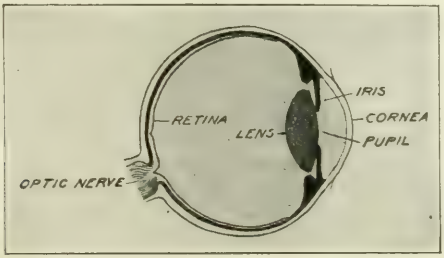


Fig. 1.—The eye: essential parts shown in section.

tures and globes and arrange the lights so as to best suit the particular conditions which have to be met, but certain principles

Fig. 2.—Pupil of eye expanded to let in plenty of light when illumination is dim.

Same pupil contracted to shut out excessive light.

* A primer of illumination prepared under the direction of the Illuminating Engineering Society. (Copyright 1912.) Applications for permission to reprint this paper should be addressed to the Illuminating Engineering Society, 29 W. 39th Street, New York. The society will publish the primer in separate pamphlet form, which will be ready for distribution September 10, 1912.

which must always be followed, may safely be laid down.[1]

Don't Judge Illumination by the Brightness of the Lamps.

Judge the light you are gettting by the way it helps you to see. Do not think because a lamp looks glaring and brilliant that it is giving you good light. It may be merely giving you too much light in the wrong place. On the other hand, a well shaded table lamp may look dim because it is well shaded, and still be giving first-class light for working purposes.

You must get enough light to see by, and as you see things chiefly by the light which they reflect, it is evident that dark colored objects which reflect light badly require more light than do light colored objects to see them comfortably. That which is quite sufficient for sewing on white cloth, for example, will not do at all for working on black cloth.

Don't Work in a Flickering Light.

See that your light is steady. If you leave a dark room and go into bright sunshine, the sensation is unpleasant to the eye; if you use a light that flickers, you get this same unpleasant sensation, perhaps as rapidly as twenty times a minute. Furthermore, the eye endeavors to adjust itself to suit the light; if the light flickers it keeps the iris of the eye "see-sawing" as it were, and the muscle that governs it gets tired and reacts on the nerves

[1] To understand these principles better, take a glance at the eye and see how it works. Figure 1 shows the parts of the eye as they would appear if it were cut through from back to front vertically.

In the process of seeing, the light passes through the cornea, pupil, and lens of the eye, to the retina, just as in a camera light passes through the lens to the sensitized film. The picture is formed on the retina, which is a layer made up of the ends of nerve fibers which gather into the optic nerve and go directly to the brain. The optic nerve sends along the picture to the brain for notice. The lens of the eye, unlike that of the camera, automatically changes in thickness to focus or make a clear image on the retina for seeing at different distances. This focusing action is called the accommodation of the eye, and when the light is dim or bad the focusing muscle vainly hunts for some focus which may make objects look clear and gets tired in trying to do it. The muscles which move the eye about also get tired in the same way and the result is eye-strain, which stirs up pain and headache just as any other over-tired muscles of the body may set up an ache.

The iris (which gives the eye its color), serves to regulate the amount of light which reaches the eye. In very dim light it opens out making the pupil big, as shown in fig 2, and in very bright light it shuts up as shown, and thus keeps out a flood of brilliant light which might hurt the retina. The protective action of the pupil is pretty good, but by no means complete, for it seldom gets smaller than shown in the illustration, however bright the light.

to cause discomfort and pain. Reading in railway trains causes similar strain; the eye muscles get tired in trying to follow the shaking page, and are likely to provoke a headache.

Don't Expose the Eyes to an Unshaded Light.

It is bad to have an unshaded brilliant light glaring into the eyes, for it throws hard labor upon them in an effort at adjustment. This applies even to common electric, gas, or oil lamps. (See **figs. 3, 4, 5.**) While artificial light may be made a good

Fig. 3.—Very bad lighting. This man receives, full in the face, both direct light from the unshaded lamp and reflected glare from the table top and papers.

substitute for daylight, you have constantly to beware lest rays that are too bright, either from the lamps or from their reflections, hurt the eyes. You can get reflections, so bright as to be harmful, from polished metal or glass, from bright varnished surfaces, or even from glossy white paper upon which the light falls.

A bright light fairly in the field of view means a very brilliant light on the retina, producing fatigue. Everyone knows the blinding sensation of looking at the sun with its sequence of

dazzling colored images. Babies are here common sufferers when careless mothers or nurses allow them to lie in their carriages with eyes exposed to the unclouded sun. Bright artificial lights, in a less degree, do the same thing to all of us. And when you get a bright light in the field of view, the pupil tries to shut it out; in so doing it renders less bright things all but

Fig. 4.—Faulty arrangement of dining-room lighting. The lamps exposed in the dome shine in the eyes. Trouble is aggravated by general darkness of the room.

invisible. Thus it is hard to see things which are nearly in line with a brilliant light, as you often find in facing an automobile headlight, or looking into a show window like **fig. 6**.

A Couple of Simple Experiments. Place an unshaded lamp in front of a picture on the wall and then stand back a few feet and note how much of the picture you can see clearly. Then hold a book or paper at arm's length so as just to cover the bright light and note the way in which the

picture clears up. Again, put an unshaded lamp about a foot in front of your eyes and try to read a newspaper just beyond it. Then shade your eyes from the lamp and try it again. You will soon find out in this way that lamps can be so placed that they will be a hindrance rather than a help in seeing. (Compare **fig. 7** with **fig. 6**.)

Best Direction of Light.

From time immemorial mankind has received its light mostly from the sky. Consequently the part of the retina on which the light from above chiefly falls is pretty well used to it, while bright light

Fig. 5.—These ladies are annoyed by the glare of the unshaded light when they look across the room. Common and faulty arrangement. Lamps should be enclosed in diffusing globes.

from below, falling on the part of the retina which commonly gets light only from grass or dark pavements, may be very irritating and unpleasant. Thus the glare from snow and sand is not only disagreeable on account of its intensity but because of the unusual direction from which it comes. Just so with a brilliant beam reflected from glossy paper on which you are writing.

Its rays strike you from an unusual direction and are harmful for that reason. Other smooth and shiny surfaces deliver an

Fig. 6.—Poor arrangement for display. You see the lamps instead of the sweets.

Fig. 7.—Excellent arrangement for display. No lamps in sight. Every garment is brightly lighted.

equally hurtful assault on that sensitive and much abused organ,—the eye.

Don't Read Facing the Light.

It is best to have the light come from above and somewhat sidewise, as it commonly does in nature, so that you will not get a brilliant reflection or glare from what you are trying to see. In reading and writing it is better to have the light come from the left, to avoid getting a shadow of the hand that holds the book or pen. Let the lamp be just far enough behind to keep direct reflections from the paper out of the eyes. (See **figs. 8, 9, 14, 15.**) But what has been said of reflections from paper applies with even more force to the case of polished metals, or the like, over which one is busy. Individual lights placed close over the work are very likely to produce these troublesome direct reflections and consequently such lights are falling into disuse. In an interior otherwise dark, their use is open to the further objection of giving bright spots of light and so producing too violent contrasts of light and shade. (See **figs. 16, 17.**)

Don't Use a Bright Light Against a Dark Background.

Almost any light will glare unpleasantly if the surroundings are thoroughly dark. As an extreme illustration, the light from a big arc lamp hung close to the sidewalk may be very annoying at night, but by day you would hardly notice it. Just so a bright lamp against a dark background may be annoying while against a light background it would not be so unpleasant.

LAMPS, FIXTURES, GLOBES, REFLECTORS.

One may choose to-day among lights of many kinds. There are at hand candles, oil lamps, open flame gas jets, upright and inverted mantle gas lamps, electric incandescent lamps of carbon and of tungsten, electric arcs of half a dozen varieties, besides mercury-vapor tubes, acetylene lamps, as used on motor-cars, and so on through a long list.

What do you wish to use a light for? To read or write by, to bring into view the working parts of a machine, to match colors, to display goods, or pictures; or merely to make a pathway safe and plain? Each case is to be studied by itself, and the effect is to be accomplished by such lamps, globes and reflectors as, properly disposed, will insure ample lighting without glare, and yet with strict economy.

However good and suitable the lamp, it will be put at a disadvantage unless the lighting fixture which carries it is designed to hold the lamp in the right position to enable one to best utilize the light which comes from it. Prettiness in a fixture is well enough; but let the fixture be serviceable first; then it may be also as pretty as you please. But don't buy prettiness if it makes war on good service.

Daylight is naturally well diffused; but artificial light, poured

Fig. 8.—A bad position for reading. In spite of the shaded lamp, glare from paper reflected into eyes, is very trying, and harmful.

out as it is from mere points, or narrow surfaces, needs to be tempered or softened by shades. And it sometimes further requires to be directed upon a desk or table or other object. In some cases it is better to adopt indirect methods, and throw the beams of a lamp upon a ceiling whence the rays are scattered. For every particular need there is ample provision amid the abounding lamps, globes and reflectors of present day designers.

Arranging Lights. Two methods are usual in arranging lamps: first, to secure general illumination by so placing the lamps that you may see with comfort anywhere in a room; second, in cases where a bright light is not necessary throughout a room, local illumination can be planned, placing the lights where they will be most used, always remembering that it

Fig. 9.—Good position in reading. No light directly hits the eyes and no glare is reflected from the book.

will not do to localize light too much, since you need for comfortable seeing a fair quantity of light broadly distributed.

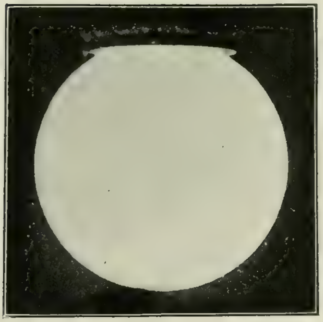
PRECAUTIONS TO BE TAKEN IN PLACING AND SHADING LIGHTS.

In any artificial lighting the lamps should be so well shaded that the eye does not see them directly nor brilliant reflections from

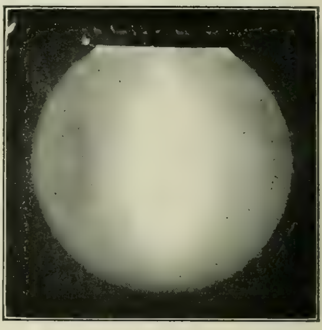
them. You can accomplish this end by putting the light in diffusing globes of, for instance, ground glass or white or opal glass or other translucent material. To secure the best diffusion, the globes should be dense enough not to reveal the form of the actual light source within, but to give the effect of the light pouring forth from the globe as a whole. (See **fig. 10.**)

Diffusing and Shading by Globes and Reflectors.

Another way of accomplishing the same result is to put a shade around the lamp, which screens it and reflects downward much of the light which would otherwise idly fall on the walls or ceiling. (See **fig. 11.**) Such shades may be of mirrors or



Opal glass globe.



Ground glass globe.

Fig. 10.—Within each globe is a lamp of the same candle-power. Note the superior diffusion of the light by the opal globe.

polished metal or white or opal glass, of ground or prismatic glass,—all of which, in a measure, work alike. Glass shades are generally preferable to metal ones, for a little light penetrates them sidewise,—just enough to keep the upper part of the room from being too dark.

Indirect Lighting

Another scheme successfully used to shield the light is to turn the light from the lamp upward on to the ceiling by means of an opaque reflector underneath. The reflector conceals the lamp, and the brightly illuminated ceiling by which the light is diffused serves as the actual source of the illumination. (See **fig. 12.**) This plan should be used only on white or very light ceilings and is subject to a heavier loss for securing diffusion than some other methods, but

often this loss is reimbursed by the thoroughness with which the ceiling diffuses the rays that fall upon it.

Don't Use Local Lighting By Itself.

General Illumination Usually Best.

In ordinary cases general illumination is the best way of lighting an interior unless some of the work in hand, as sewing dark goods or reading very fine print, demands exceptionally strong lighting

Fig. 11.—General illumination by direct lighting; lamps concealed in diffusing glass reflectors.

in some parts of the room. In this case local lights may be added, but they ought not to be used without pretty strong general illumination. The commonest sort of localized lighting is that furnished by a table lamp. Such a lamp should always be shaded to keep the direct light out of the eyes,—best by a translucent shade which will add something to the general illumination.

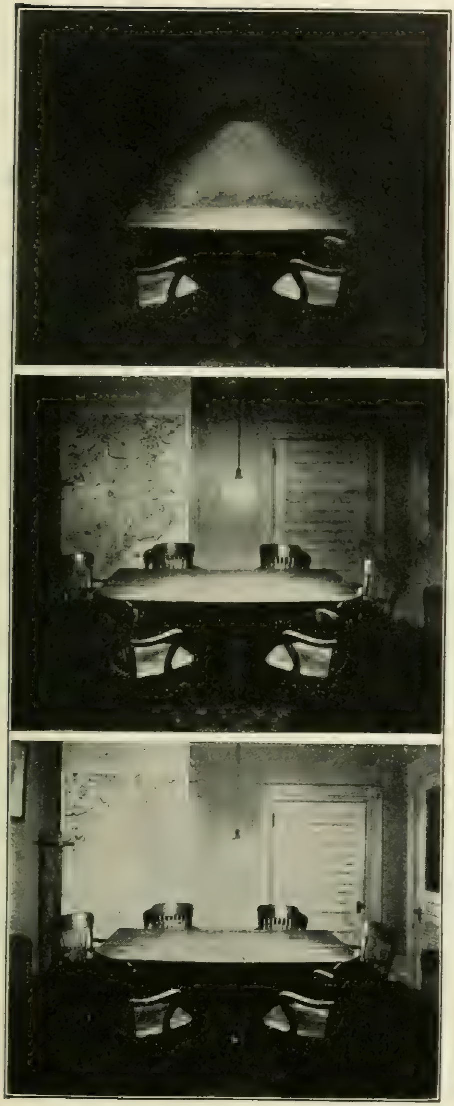
In any one of these plans for general illumination, lights should be so placed as to give at least fairly uniform lighting every-

where in a room, otherwise there may be strong and jarring contrasts of light and darkness.

In using shades open at the bottom, such as are very common, their shape and character can be so chosen as to distribute the light precisely as desired; this result can in less degree be accomplished by using enclosed globes or by indirect lighting.

Fig. 12.—General illumination by indirect lighting; lamps are concealed in opaque reflectors and the light is diffused from the ceiling.

Any of the schemes here sketched can be made to give good results. The choice between them turns upon just what task is required of the light and what its surroundings are to be. Ordinarily, lighting from shades open at the bottom gives a stronger light than other methods, but you must carefully avoid glare in these cases. Lighting by wholly indirect means, in which all the rays are diffused from the ceiling demands lamps of extra power for the same illumination, but requires little care to avoid glare. Rooms lighted from diffusing globes take an intermediate position with respect to freedom from glare.



(a) Concentrating reflector: lights a small area brilliantly.

(b) Semi-concentrating reflector: lights a larger area less brilliantly.

(c) Distributing reflector: lights a wide area moderately.

Fig. 13.—Reflectors put the light where you want it; (a), (b), and (c) have lamps of the same candle-power. (These pictures are intended only to show, in a general way, the effect of different types of reflectors.)

Misplaced Brackets. For a lamp to do its best work, it should not be too near a wall, especially if this wall is dark. Hence only very small rooms can be well lighted by the usual side brackets, say 4 to 6 feet high. In a large room the eye cannot avoid glare from such brackets unless their lamps are so heavily shaded as to dim the room. In large rooms where brackets can be placed high enough to be out of the general view,

Fig. 14.—Don't place a desk lamp like this; it glares from the paper and shines in your eyes besides.

they may be used to advantage; and they are often convenient for occasional use, as in bed rooms, when the room is also lighted by other means.

ECONOMY AND EFFICIENCY.

Don't Waste Light by Using the Wrong Reflectors.

By using reflectors you can put the light from a lamp where it will do the most good, much as an automobile headlight sends the

light along the road just where it is wanted. In **fig. 3**, there is a lamp without any shade or reflector and you will see that the light goes in all directions, only a small part of it falling on the level of the table where it is needed. The rest hits the walls and is reflected about the room losing intensity at each reflection. Obviously an unshaded lamp does not throw the light where it is wanted. To ensure the light falling upon the table you must use a reflector that will bring it there.

Fig. 15.—If you must use a desk lamp, put it in this position. If an open reflector is used let it be of the diffusing type. Better still is a reflector with a diffusing glass bottom.

Of such reflectors there are three general types, either of glass or of metal, which we may call concentrating, semi-concentrating, and distributing. (See **fig. 13**, (a), (b) and (c).) The first acts almost like an automobile headlight, throwing its light downward into a comparatively small area. The second kind spreads out the light over a much wider area, of diameter perhaps as great as the height of the lamp above the table, while the third

is planned to light a comparatively big area not very intensely at any one spot.

No reflector ever increases the total light that streams out of a lamp; it only puts the light where it is needed instead of letting it go unguided.

Fig. 16.—More light in the eyes than on the work and not enough light in the room. Sharp shadows and much glare from the polished metal. Discomfort to the worker: loss to his employer.

Don't Use Shallow Reflectors.

All reflectors should come far enough down over their lamps to prevent you from seeing the bright sources of light themselves without actually looking upward.

Height of Lamps. With proper reflectors, their height above the table, counter, or bench, ordinarily makes little difference since

it is the purpose of the reflectors to send the light where it will do the most good.

Effect of Dark Walls and Colored Globes. Because dark walls absorb light strongly instead of reflecting it they demand much stronger lamps for sufficient illumination than do light walls. (See **fig. 18.**) A very dark wall-paper or a dark wood finish may require three or four times as much light as a really light finish. Dark reds, greens, and browns reflect only 10 to 15 per cent. of the light which falls on them. White, cream

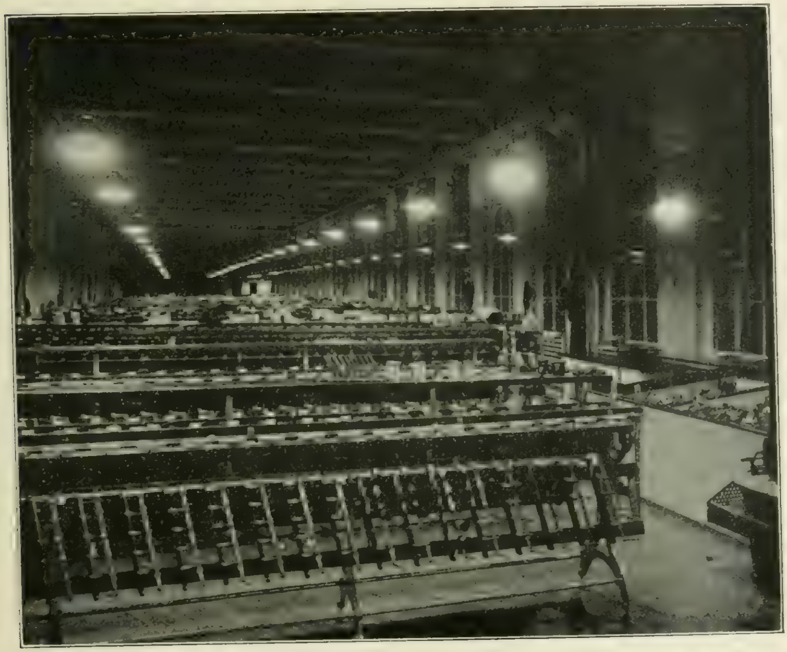


Fig. 17.—Example of good general illumination in a factory; the whole area is uniformly and brightly lighted.

color, and light yellowish tints may reflect over one-half the light.

Likewise, deeply tinted globes and shades absorb much light,—a fact which must be borne in mind in considering economy.

Don't Let Lamps and Globes Get Dirty.

Dirt on lamp chimneys, electric bulbs, globes, or reflectors, absorbs and wastes much light. The country over, it is safe to

say that millions of dollars are wasted every year by letting lamps become foul and dust laden. Nor is there any economy in using electric bulbs until they blacken. It pays to renew promptly, blackened bulbs and defective gas mantles.

Don't Save Light at the Expense of Your Eyes.

Real and False Economy. Saving light at the cost of eyesight is false economy. To get good lighting it is generally necessary to diffuse the light from the lamps either directly, by opal or ground glass shades, or indirectly by turning the light

Fig. 18.—Each of these two little rooms receives the same light. Dark walls absorb most of the rays of light in left hand room.

first on the ceiling or wall. The use of ground glass involves the absorption of 15 to 20 per cent. of the light to secure diffusion, opal glass of various kinds from 20 to 40 per cent., while some forms of art glass and most diffusing ceilings absorb more than half the light that falls upon them. Even though all these appliances absorb light in the process of diffusion, there is gain in their use because they yield rays more grateful to the eyes. But your eyes may tire easily even with good lighting. If so, consult an

oculist and don glasses if you need them. Eyestrain often comes from defective eyes as well as from faulty lights.

Economy in Selecting Lamps. In gas lighting there is no economy in using open flame burners unless the exposure is such that gas mantles would often be broken. Similarly, with electric lights it is very wasteful in most cases, to use carbon filament lamps when tungsten lamps are available. The carbon lamps cost less to install or replace, but much more for electric current.[2]

AMOUNT OF ILLUMINATION REQUIRED.

The common unit of illumination is the foot-candle, meaning thereby the light which the object would receive from a standard candle at the distance of one foot. This is the measuring rod, as it were, by which comparisons are made.

No absolute rule can be laid down for the number of foot-candles required for good seeing. Individuals differ widely in their requirements; and the conditions under which the light is used cause still greater variations in requirement. However, where lighting arrangements are well planned it has been found by experience that ordinary reading, writing, or work on white or light colored material, can comfortably be carried on by most people with an illumination of 2 to 3 foot-candles. For sewing dark goods, or reading fine type, 5 foot-candles are none too much, while for drafting, engraving, watchmaking, working on black cloth, and the like, from 7 to 10 foot-candles should be furnished.

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[2] The amount of electricity taken by an electric lamp is expressed in watts. Most electric lamps now manufactured have the number of watts which they are rated to consume printed on a label on the bulb. The old-fashioned carbon filament incandescent lamp of 16 candle-power has the candle-power on the label, and takes from 50 to 60 watts.

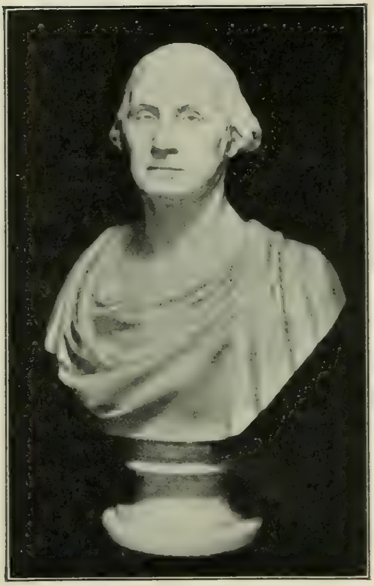
How to Figure Cost of Light.

To determine the cost of operating an electric lamp, divide the number of watts it consumes by 1000 to reduce to kilowatts, and multiply the number of hours the lamp is to be operated by the kilowatts, to obtain the kilowatt-hours of electrical energy. The kilowatt hours multiplied by the rate per kilowatt-hour which is charged, gives the cost of operation for the stated time.

The consumption of gas lamps is expressed in cubic feet of gas per hour. The number of cubic feet of gas per hour taken by a burner, divided by 1,000, and multiplied by the cost per thousand cubic feet of gas, and by the hours of burning, gives its cost of operation for the stated time.

The consumption of open flame burners is commonly taken at 5 cubic feet per hour Upright single mantle burners usually take from 3½ to 5 cubic feet per hour, though some smaller ones take less. Most individual inverted gas mantle burners take from 3 to 3½ cubic feet per hour.

Artistic Effects. In a room suitably arranged for comfortable seeing, you may have plenty of light, but the general effect may be displeasing. The illumination may quite fail to bring out the good points of the room in architecture and decoration, or may play pranks with the appearance of persons or things in the room. (See **fig. 19**.) One may not object to ghastly tints in a factory, but in lighting a drawing room such effects would not be tolerated. Hence one often should sacrifice



Bust lighted from above and in front.

The same bust lighted from directly overhead.

Fig. 19.—Bad lighting defeats good art.

strict economy to get the most pleasing effect in the room. The fixtures that carry the lights should harmonize with their surroundings if the general effect is to be agreeable. Handsome fixtures have a decided decorative value whether their lamps are lighted or not. As strongly colored objects give something of their own hue to all the light which they reflect, the color of lamp shades, walls, and furnishings, plays an important part in the artistic effect.

TRANSCRIPTIONS OF THE

Illuminating Engineering Society

VOL. VII. OCTOBER, 1912. NO. 7

COUNCIL NOTES.

The next meeting of the council will be held in the general office of the society, 29 West 39th Street, New York, November 15.

A special meeting of the council was held (September 19) at the Hotel Clifton, Niagara Falls, Canada, during the annual convention. The following two resolutions were adopted:

1. That the council instruct the committee on constitutional revision to draw up (in conjunction with the council executive committee) such constitutional proposal as will, if adopted by the society, permit the formation of some sort of sustaining membership in the society.

2. That the constitutional revision committee be requested to frame some proposal whereby the manner of reporting section discussions may be altered at the discretion of the council, if the proposal be adopted by the society.

The intent of the latter resolution was to make the reporting, stenographically, of section monthly meetings optional. The constitution of the society at present requires that these meetings shall be reported stenographically.

Both these resolutions were transmitted to the committee on constitutional revision.

Present at the meeting were: V. R. Lansingh, president; E. P. Hyde, H. E. Ives, Norman Macbeth, George S. Barrows, L. B. Marks, Jas. T. Maxwell, W. J. Serrill, Preston S. Millar, general secretary; and Mr. C. O. Bond by invitation.

A regular meeting of the council was held in the general office of the society, New York, October 14.

The minutes of the regular and special meetings in June and September, respectively, were adopted. The minutes of the re-

port of the executive committee covering its activities during the summer were also adopted.

Reports of progress were received from the new membership, convention, reciprocal relations, advertising, section development, glare, and illumination primer committees.

Considerable discussion was devoted to the proposals to amend the constitution contained in a report from the constitutional committee. The proposals involved the establishment of a sustaining class of membership in the society and a change in the fiscal year. After making several changes in the committee's proposals, the council directed that all the proposals be submitted to the vote of the society at the forthcoming election.

Three resolutions pertaining to publication policy of the society were adopted. One was that council inform the publication committee that all reasonable requests by responsible parties to reprint any of the society's papers, or parts of them, be granted with the proviso that proper credit shall be given the society's publication. The second resolution called for the printing of a statement in the TRANSACTIONS to the effect that the society does not assume the responsibility of the views or opinions expression in its papers and discussions. The third had to do with trade names. It was decided to admit trade names in the society's papers and discussions when the things referred to could not otherwise be accurately described or identified.

A report on the membership and the expenses of the society was received from the assistant secretary. The total membership including the applicants elected and the resignations accepted at the meeting was 1,494. Of this number 140 names were ordered dropped from the roll, unless their dues be received before December 31.

The treasurer was authorized to borrow money on the society's two bonds to defray current running expenses.

Those present at the meeting were V. R. Lansingh, president; E. P. Hyde, George S. Barrows, Norman Macbeth, Jas. T. Maxwell, C. J. Russell, Wm. J. Serrill, H. E. Ives, L. B. Marks, Preston S. Millar, general secretary; and A. E. Kennelly, C. H. Sharp, C. O. Bond and A. S. McAllister by invitation.

SECTION ACTIVITIES.

The boards of managers of the several sections of the society are arranging the section programs for the season 1912-1913. It is expected that these programs will be printed and distributed in the near future.

CHICAGO SECTION.

The Chicago section held a joint meeting with the Western Railway Club in the Karpen Building, Chicago, October 15. A paper on "Head-Light Tests" was presented by Mr. C. M. Larson of the Wisconsin Railway Commission. The paper was discussed by several members of the club and the society. About one hundred and fifty members and guests of the two organizations were present.

The final arrangements for the November meeting have not yet been announced. The paper of the evening will in all probability be one on "Hospital Lighting" by Mr. Meyer J. Sturm.

NEW YORK SECTION.

At a special meeting of the New York section which was held August 1, Mr. Leon Gaster, honorary secretary of the Illuminating Engineering Society, of London, delivered an address on the work of that society and the progress of illumination in Europe. Mr. Gaster reviewed the work of the society in a very interesting manner. He referred particularly to the work which it had done toward procuring legislation on illumination matters. In referring to the legislative reports on illumination of the countries abroad, notably England, France, Germany and Belgium, Mr. Gaster intimated that it would be well for the Illuminating Engineering Society to encourage similar legislation in America. In discussing the points raised in Mr. Gaster's address, a number of the members of the society drew attention to the fact that progress in lighting legislation in America must of necessity be comparatively slow; numerous state governments must be approached before anything definite in the way of national lighting legislation can be accomplished. One other fact brought out was that in America to-day there are many admirable examples of exterior and interior illumination which are not surpassed by any of their kind abroad. These installations, it was contended, are to be attributed largely to commercial enterprise.

The first regular meeting of the present season was held at Keen's Chop House, 70 West 36th Street, New York. Two of the recent convention papers, "The Present Practice in Small Store Lighting" by Messrs. Law and Powell, and a "Symposium on High Pressure Gas Lighting" were reviewed and discussed by a number of members.

The following tentative program has been arranged by the board of managers.

November 14: A joint meeting with the National Electric Association. At this meeting there will be a demonstration of lighting effects by Mr. Preston S. Millar.

December 13: A joint meeting with the American Society for the Conservation of Vision.

January 9: A joint meeting with the National Commercial Gas Association.

February 13: A joint meeting with the Municipal Art Society.

March: A joint meeting with the lighting section of the American Society of Mechanical Engineers.

April: A joint meeting with the lighting section of the Institute of American Electrical Engineers.

May: A joint meeting with the American Library Association.

At the joint meetings listed above it is proposed to have one paper by a member of the Illuminating Engineering Society and one paper by a representative of the other participating organization.

New England Section.

The following tentative program has been announced by the board of managers of the New England section.

November: "Gas and Electric Meters." The subject will be handled by representatives of several meter manufacturing companies.

December: "Head-Lights, Lighthouses, and Lenses," by an inspector of the United States Government.

January: "Vision and Defects of Vision."

February: "The Light of the Stars."

March: "New Types of Arc Lamps."

April: "Methods of Light Best Adapted to Reinforce Daylight at Dusk."

May: "Photographic Lighting."

PHILADELPHIA SECTION.

The first regular monthly meeting of the Philadelphia section this season was held on the athletic grounds of The Philadelphia Electric Company, Kelley's Lane and West Chester Pike, Delaware County, Pa., Saturday, September 28, 1912. In the afternoon, a ball game between the teams of The United Gas Improvement Company and The Philadelphia Electric Company was witnessed. There were 160 people present at the game, 30 of whom were ladies. Dinner was served at 6 o'clock, with about 70 members and guests present. After dinner, those in attendance adjourned to the grandstand on the ball field, and were addressed by Prof. Monroe B. Snyder of the Central High School, on "The Light of the Stars." Mr. George S. Bliss of the Weather Bureau gave a little talk about "Weather" and Dr. Herbert E. Ives presented a very interesting description of the recent convention held at Niagara Falls. After the meeting everyone took advantage of the opportunity to view the stars through the telescopes which were provided.

At a meeting which was held October 18, in the Franklin Institute, Dr. C. E. Ferree of Byrn Mawr College presented a paper entitled "Tests for the Efficiency of the Eye Under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort." Dr. Ferree's paper had been prepared for the convention of the society. A second paper on "The Psychology of Vision and Causes other than Defective Illumination for Eye Strain" was read by Dr. W. Zentmayer of Philadelphia. Both papers were received with interest. During the meeting there was an exhibition of ophthalmological apparatus. At the dinner preceding the meeting thirty members and guests were present.

PITTSBURGH SECTION.

The Pittsburgh section held its first meeting of the present season in the auditorium of the Engineer's Society of Western Pennsylvania, Oliver Building, October 11, 1912. The following papers, which had been presented at the Milwaukee convention of the Association of Iron and Steel Engineers, October 3, were reviewed and later discussed by members of the society

and representatives of several lamp manufactures: "Modern Illumination in the Iron and Steel Industry."—By C. E. Clewell; "The Incandescent Lamp in the Steel Industry."—By Ward Harrison; "Curves and Data for Illumination Caluculations".—By C. J. Mundo. Preceding the meeting Professor H. S. Hower gave a fifteen minute talk on "The Nature of Light."

The following tentative program has been arranged by the board of managers:

November .... "The Use of Lenses in Illumination"
By Prof. H. S. Hower.

December .... "Store Illumination"
This subject will be presented by a representative of the Nelite Works of the General Electric Company.

January .... "Street Lighting"
By Mr. C. E. Stephens.

February .... "Gas Illumination"

March .... "The Incandescent Lamp in the Central Station Business"

April .... "Some Phases of Railroad Illumination"

May .... "Physiological Aspects of Illumination"

Preceding each meeting Prof. H. S. Hower will give a short elementary lecture on light. One joint meeting is being arranged with the Pittsburgh branch of the American Institute of Electrical Engineers.

THE I. E. S. ILLUMINATION PRIMER.

"Light: Its Use and Misuse," the primer on illumination which the Society distributed recently to its members, to manufacturing companies, professional societies, civic associations, and other organizations, has occasioned a lot of very flattering criticism. The editorial columns of several technical and trade journals have referred to the primer in terms of rather high commendation. From people who are generally supposed to be but little interested in the subject of illumination have come numerous letters expressing pleasure and admiration for the clear and interesting manner in which the primer is presented. Requests have been received from the engineering and physics departments of a number of universities and colleges for quantities of the primer to be distributed to students. Several lighting companies have ordered editions which are to be issued to their customers. Two

manufacturers of lighting accessories have been granted permission to print and send out large editions to their consumers and the public at large. These companies have intimated that they believe that the primer will create a demand for better illumination. One large lamp manufacturing company in London has cabled for a set of the plates of the primer illustrations and permission to print a large edition which is to be mailed free to its customers. All this diverse interest has been manifested within two weeks after the initial circulation of the special edition of the primer; and the present indications are that the primer will be circulated widely by the large lighting and manufacturing companies throughout the country. It is likely, too, that it will be printed in several languages and distributed extensively abroad.

THE 1912 I. E. S. CONVENTION.

The sixth annual convention of the Illuminating Engineering Society was held at the Hotel Clifton, Niagara Falls, Canada, September 16-19 inclusive. An excellent program of papers was presented and the attending discussions were altogether lively and interesting. Between the sessions a fair compliment of amusement was provided. Several excursions and inspection tours were made to various places of interest about the Falls. The registration figures showed that 105 members and 57 guests, including 22 ladies, were in attendance at the several sessions. The convention, although it was the first one held at a place removed from a city represented by a section, was pronounced the most successful one in the history of the society. The program is given below.

CONVENTION PROGRAM.

Monday, Sept. 16, Opening Session, 10 a. m. to 12.30 p. m.

Addresses of Welcome:

Mr. O. E. Dores, President of the Board of Trade, Niagara Falls, Ont.

Mr. G. F. Nye, President of the Board of Trade, Niagara Falls, N. Y.

Response to Addresses of Welcome:

Mr. Wm. J. Serrill, Philadelphia, Pa.

Presidential Address:

Mr. V. R. Lansingh, Cleveland, Ohio.

Reports of Committees.

Report of Committee on Progress:
    Dr. Louis Bell, Chairman.
Report of Committee on Nomenclature and Standards:
    Dr. A. E. Kennelly, Chairman.

2.30 P. M. TO 5 P. M.

A Symposium on High-Pressure Gas Lighting:
    (a) In Great Britain, by Mr. F. W. Goodenough.
    (b) In Germany, by Oscar Klatte.
    (c) In the United States, by Mr. R. N. Zeek.
The Deterioration of Gas Lighting Mantles in Service:
    Mr. R. F. Pierce.

8 P. M.

Reception and Dance.

TUESDAY, SEPT. 17, 10 A. M. TO 12.30 P. M.

The Methods of Research:
    Dr. E. P. Hyde.
The Diffuse Reflection and Transmission of Light:
    Dr. P. G. Nutting.
Heterochromatic Photometry and the Primary Standard of Light:
    Dr. H. E. Ives.
A New Method and an Instrument for Determining the Reflecting Power of Opaque Bodies:
    Dr. P. G. Nutting.
A Study of Natural and Artificial Light Distribution in Interiors:
    Mr. M. Luckiesh.

2.30 P. M. TO 5 P. M.

Vision as Influenced by the Brightness of Surroundings:
    Dr. Percy W. Cobb.
The Determination of Illumination Efficiency:
    Mr. E. L. Elliott.
A Proposed Method of Determining a Coefficient of Diffusion for Lighting Accessories:
    Mr. E. L. Elliott.
Some Reflecting Properties of Painted Interior Walls:
    Mr. Claude W. Jordan.

7 P. M.

Banquet.

WEDNESDAY, SEPT. 18, 10 A. M. TO 12.30 P. M.

Report of the Committee on Illumination Primer. A special edition of the primer was distributed.
Report of the Illumination Committee of the Association of Iron and Steel Electrical Engineers:
    Mr. C. J. Mundo, Chairman.

Present Practise in Small Store Lighting with Tungsten Filament Lamps:
Messrs. Clarence L. Law and A. L. Powell.

The Engineering Principles of Indirect and Semi-Indirect Lighting:
Mr. T. W. Rolph.

2.45 P. M.

Trolley ride on the Niagara Belt Line around the Gorge.

8 P. M.

Color Values of Illuminated Surfaces:
Mr. Bassett Jones, Jr.

Special meeting of members for the discussion of matters pertaining to the welfare and advancement of the Society.

THURSDAY, SEPT. 19, 10 A. M. TO 12 NOON.

The Lighting of the Buffalo General Electric Company's Building:
Mr. W. D'A. Ryan.

Theory and Calculation of Illumination Curves:
Mr. Frank A. Benford, Jr.

Characteristics and Tests of Carbons for Enclosed Flame Arc Lamps:
Messrs. Allen T. Baldwin and R. B. Chillas, Jr.

Tests for the Efficiency of the Eye under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort:
Dr. C. E. Ferree.

Before adjournment a set of resolutions were adopted extending to the convention committee a most hearty vote of thanks for the general excellence and success of the convention.

HETEROCHROMATIC PHOTOMETRY AND THE PRIMARY STANDARD OF LIGHT.*

BY HERBERT E. IVES.

It may safely be asserted that there are two problems in the science of light measurement which in importance overshadow all others. These are: first, the problem of the photometry of lights of different colors and; second, the problem of securing a scientific primary standard of light.

The solution of these problems is of considerable importance to the illuminating engineer, for his fundamental working quantities are dependent for their specification upon photometric methods and standards. This has been recognized in the past in the various papers which have been published in the TRANSACTIONS dealing with photometry and light standards. Among these papers are several by the present writer, in which reference has been made to researches being carried on in heterochromatic photometry and to a possible scientific primary standard of light. The work referred to, which has been under way for nearly three years, has now reached a practical conclusion. It will be described in detail in certain scientific journals, but it is appropriate that a summary of the results should be printed here. Such a summary follows:

THE PHOTOMETRY OF LIGHTS OF DIFFERENT COLOR.

Requirements to be met by a method of light measurement.—An analysis preliminary to the investigation suggested the following as desirable qualities of a method of heterochromatic photometry.

1. The results should correspond as nearly as possible to some useful value.
2. The method should have high sensibility.
3. The results should be accurately reproducible.

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

4. Things measured equal to the same thing should measure equal to each other.
5. The sum of the measurements of the parts should equal the measured value of the whole.

Four photometric methods were studied from the standpoint of these criteria, namely: visual acuity, critical frequency, equality of brightness, and flicker. Over and above the study called for by these requirements, investigations were made of the behavior of the four methods under varied conditions of illumination and field size which, from the inevitable introduction of the physiological characteristics of the eye, must play a large part in the study of this question.

The scale of color used was the spectrum of a known energy distribution. This is the most desirable set of test colors for several reasons, among others because all colors are made up of mixtures of spectral colors, and results obtained on the spectrum may be applied, if the photometric method possesses the requirements given above, to any other colors of known spectral composition.

The application of these criteria to the four photometric methods resulted in the elimination of all except the flicker method. For instance, the methods of visual acuity and critical frequency are excessively insensitive. An accuracy greater than 5 per cent. is quite beyond reasonable expectation. Furthermore, by neither of these does the whole equal the sum of the parts. In the case of visual acuity the addition of two illuminations of equal brightness may, because of the chromatic aberration of the eye, produce an illumination of less detail revealing power than either alone. This leaves the methods of equality of brightness and flicker. On the score of sensibility and reproducibility the latter quite distances the former. In order, however, to answer the questions raised by the other requirements, some of the characteristics of these two methods under varied conditions should be reviewed.

The effect of reducing the working illumination with the equality of brightness method is to increase the apparent relative brightness of the blues—the Purkinje effect. The flicker method develops a peculiarity of just the opposite kind. At low illumi-

nations the results of the two kinds of photometers are widely divergent. At high illuminations (around 25 meter-candles) the results by the flicker method and equality of brightness method approach each other; and it has been found that if the mean of a large number of observers be taken by both methods the two means agree. Further, it has been found that if the equality of brightness measurements be made by steps of small hue difference, the results again agree with the flicker method. In other words, at the high illuminations specified, by minimizing the psychological disturbing factors of the equality of brightness method (as by taking a large number of observations) one arrives at the result given at once by the flicker method. This gives the answer to requirement 1, in the case of the flicker photometer; the flicker photometer measures relative *brightness*.

Requirements 4 and 5 may now be discussed. They are both met by the flicker method. They are not met by the equality of brightness method, as ordinarily carried out. For instance, with the latter, if the color of the comparison light is changed, an observer will form a new criterion of relative brightness for the spectral colors. Only by allowing an interval of time to elapse between each set of observations and taking many sets can a final average be obtained which has the qualifications 4 and 5, and when obtained it is the same as that which the flicker method gives at once.

As the outcome of this work the following conditions are suggested for adoption as standard in heterochromatic photometry.

1. The use of the flicker photometer.
2. An illumination of 25 meter-candles. (Understood to be on a white surface, such as magnesium oxid.)
3. A photometric field of 2 deg. diameter, surrounded by an approximately equally bright area of 25 deg. diameter. (The small field is chosen because with it the effect of varying the illumination is largely eliminated. The bright surrounding field is introduced because it has been found to increase the comfort and sensibility of reading, without the disadvantages of the large photometric field.)
4. The observer must have an average eye.

Adherence to this last condition, or its equivalent, is imperative, since individual eyes vary considerably in their relative color sensitiveness. Condition 4 may be approximated by taking the results of as large a number of observers as possible. Or the characteristics of the average eye may be established, and the results of an observer corrected to normal from similar knowledge of the characteristics of his eye. This amounts to determining the spectral luminosity curve of the average eye and that of each observer in a laboratory. Fig. 1 gives the average spectral luminosity curve of eighteen observers, for a normal equal energy spectrum, as recently determined by

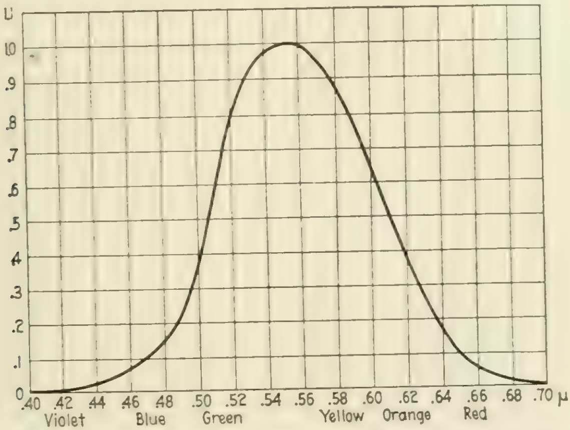


Fig. 1.—Relative luminous efficiencies of the various spectral radiations. (Average normal spectral luminosity curve of eighteen observers for an equal energy spectrum.

the writer. The number of observers is considered sufficiently large to warrant proposing the adoption of this as the standard luminosity curve.

Experiment shows that, as should be the case with the five above requirements met, it is possible to correct the results obtained by an observer to normal by means of his luminosity curve and the energy distribution of the source under measurement. Consequently, if every laboratory ascertains the spectral luminosity curve of its observers and the spectral energy distribution of the light source measured, all results can be corrected to the average observer defined by the luminosity curve given in fig. 1.

Another method by which uniformity of results in heterochromatic photometry may be achieved is by the development of some radiometer so screened as to be sensitive to the different spectral regions exactly in accordance with the data of fig. 1.

DISCUSSION.

The adoption of these conditions for colored light photometry is urged by the writer, but it is desired to have clearly understood the limitations and the compromises which they involve. First of all it is recommended that the photometry of lights of different color be confined to the standardizing laboratory. In such a laboratory the characteristics of the observers' eyes would all be known and, by the standard method, secondary standards or colored glasses would be calibrated of uniform relative value. Other observers would use these for the practical photometry of light of different color. By such a procedure all practical photometry would be reduced to the photometry of lights of the same color, for which all eyes, normal or color blind, are equally available and which may be carried on at any illumination.

Second, the consequence of using such colored standards or colored glasses will be that all measurements made would apply to the high illumination condition taken as standard. It could happen, for instance, that when working at very low illuminations, a yellow and a blue light which were pretty certainly differently bright would measure alike. But by adopting as standard an illumination corresponding in order of magnitude to the vast majority of normal working conditions, as 25 meter-candles does, the necessity for applying corrections is confined to the abnormal and less frequently met cases. It must be remembered that the Purkinje effect is only noticeable with ordinary illuminants at excessively low illuminations, so that corrections for this cause would always be small. There appears to the writer to be very little objection to a working rule of this sort: at an illumination of 0.1 meter-candle there is required x per cent. more tungsten lamp illumination than arc light illumination *as measured*, provided such corrections apply only to the cases where the photometry would be rough at best.

It is impossible to avoid "quality factors" of some sort in all

the variations which may occur in illumination conditions and use (except in the improbable event of some instrument being developed which behaves in every way like the eye). For instance, if visual acuity is to be the criterion, it might easily be necessary to give one light a handicap of 50 per cent. over another of different spectral quality, but of the same measured brightness. It is, however, the part of common sense to adopt as standard those methods and conditions of most general occurrence and use. In the present case the objector may be asked to suggest any better compromise than the one here urged.

THE PRIMARY STANDARD OF LIGHT.

Two practical requirements have heretofore ruled supreme in the choice of primary standards of light. The first is that the standard should be reproducible. The second is that its color should be close to that of the common illuminants. The first requirement is, of course, essential. As to the second, given a satisfactory method of heterochromatic photometry, it loses its importance. From a purely utilitarian point of view, one might claim that immediately any sort of standard is found to be accurately reproducible the long search for a satisfactory primary standard of light might be dropped. From the scientific standpoint, however, the existence of a satisfactory photometric method, far from closing the discussion on primary standards as no longer of moment, makes possible the specification of a new and rational type of standard. From the scientific standpoint the present so-called primary standards, such as the Hefner, are unsatisfactory in that there is nothing fundamental in their character. While a large part of our modern units and standards are directly founded on the centimeter-gram-second system, light standards are wrapped up in fuel composition and burner dimensions.

Now, the sensation of light is caused by radiant energy of a certain quality. Radiant energy is measurable in the fundamental units of length, mass and time. It has, therefore, seemed to many who have thought about the matter that the light standard should be fixed by the measurement of light as radiation. In order to do this it is necessary to have a means of evaluating the

radiation as light, for, through the introduction of the physiological characteristics of the eye, each different spectral radiation has a different light value or luminous efficiency. It is just here that the establishment of a method of heterochromatic photometry assists toward the rational standard of light. Resolving light into its two parts—physical—namely radiation, and physiological, namely, the relative light value of different radiation, it is the method of photometry that enables us to establish the latter.

The specification of a radiation standard, by which light is specified and measured as radiation, is arrived at through the study of the question of luminous efficiency. As the writer has pointed out in papers before this society, the most satisfactory measure of luminous efficiency is to express the efficiency of a radiation of a source in terms of the most efficient possible radiation. When so expressed the luminous efficiencies of different sources are directly as their lumens per watt, as should be the case. The curve of fig. 1, which is plotted with maximum value unity, is, on this understanding, a table of luminous efficiencies of the different spectral radiations.

Consider now a flux of radiant energy of value E, measured in *c g s* units, *e. g.*, watts. Its value as light flux is given by the introduction of the specific luminous output of the radiation K expressed in lumens per watt, or

$$\text{Flux of light} = \text{K E}.$$

Now K may be expressed as the product of the luminous efficiency of the source and the maximum possible specific luminous output or

$K = \mu K_{max}$ where μ = luminous efficiency and K_{max} is the lumens per watt of the ideal monochromatic green radiation,

or the light flux may be expressed as follows:

$$\text{Luminous flux} = \mu K_{max} E$$

μ is determined by the standard photometric method, E is measured in ergs per second, or in watts, K_{max} is a constant depending entirely on the "primary" standard used (*e. g.* Hefner) and on the unit of power (e. g. watt).

The proposal which it is the purpose of this paper to bring before the Illuminating Engineering Society is as follows:

In the defining equation just given,

1. Make K_{max} = unity
2. Express E in watts.

Whence,

The unit of luminous flux is the flux from a source radiating energy of maximum luminous efficiency at the rate of one watt.

Equivalent definitions are:

............the flux from a source of ***radiant*** luminous efficiency μ ***radiating*** energy at the rate of $\frac{1}{\mu}$ watts.

............the flux from a source of ***total*** luminous efficiency μ ***consuming*** energy at the rate of $\frac{1}{\mu}$ watts.

Put in more practical terms this proposal is that for the present lumen be substituted one somewhere nearer 800 times as large. By so doing the same number expresses at once the "Lumens" per watt of a source and its efficiency on an absolute scale (the ideal source gives one lumen per watt).

The practical achievement of the suggested standard is dependent chiefly upon the accuracy attainable in measuring radiant energy. It may be done in either of two equivalent ways. First, a monochromatic radiation of known luminous efficiency (as determined from the average luminosity curve) may be measured, both in light and energy units. The green mercury radiation is very well suited for such a measurement. Second, any radiation may be measured through an absorbing screen which transmits the various spectral radiations exactly in proportion to their luminous efficiency.

SUMMARY.

The present paper cannot, for lack of space, be more than a summary. In order that the subject matter may be gone into more thoroughly by those interested, a list of papers is appended in which the matters mentioned are discussed in detail. This communication is for the purpose of setting before the Illuminating Engineering Society the two proposals.

1. That the conditions of heterochromatic photometry outlined above be adopted as standard.

2. That the unit of luminous flux be specified in terms of flux of radiation and in terms of luminous efficiency, as outlined above.

LIST OF ARTICLES SETTING FORTH THE SCIENTIFIC BASIS FOR THE PROPOSALS HERE MADE.

Drysdale—"Luminous Efficiency." *Illuminating Engineer*, London, 1908, p. 164.

Nutting, P. G.—"The Luminous Equivalent of Radiation." *Bulletin* Bureau of Standards, V, p. 261.

Strache—"Proposal for Primary Standard of Light." *Proceedings*, American Gas Institute, 1911, part 2, p. 401.

Houstoun—"Absolute Measurement of Light." *Proceedings*, Royal Society, A, vol. 85, p. 275, 1911.

Ives, H. E.—"The Status of Heterochromatic Photometry." *Electrical Review*, Sept. 20, 1910.

"Special Luminosity Curves Obtained by the Equality of Brightness and Flicker Photometer." TRANS. I. E. S., October 1910.

"Studies in the Photometry of Lights of Different Color."

I. "The Equality of Brightness and Flicker Photometer." *Philosophical Magazine*, July 1912.

II. "Spectral Luminosity Curves by the Method of Critical Frequency." *Philosophical Magazine*, Sept. 1912.

III. "Distortions in Spectral Luminosity Curves Produced by variation in the Character of the Comparison Standard and the Surrounding Field." *Philosophical Magazine*. (To appear.)

IV. "The Addition of Luminosites of Different Color." *Philosophical Magazine*. (To appear.)

V. "The Luminosity Curve of the Average Eye." *Philosophical Magazine*. (To appear.)

(Above papers abstracted in *Physical Review*, 1911-12.)

"Luminous Efficiency." TRANS. I. E. S., 1910, Vol. V, p. 113.

"Luminous Efficiency." *Electrical World*, June 15, 1911.

"Energy Standards of Luminous Intensity." TRANS. I. E. S., April, 1911.

"The Primary Standard of Light." *Astrophysical Journal*, September 1912.

DISCUSSION.

MR. F. E. CADY: I would like to add in connection with one point mentioned on the fifth page of Dr. Ives' paper data on two pieces of blue glass which were intended to be used in connection with standardizing tungsten lamps in terms of 4-watts-per-candle carbon lamps. These glasses were initially measured and found to be of the same color. One piece was then measured by eight observers in the laboratory and the other piece was sent to the Bureau of Standards, where it was measured by seven observers. The results of the measurements showed a difference of only 1.2 per cent. between the average of the results obtained in Washington and in Cleveland. This is interesting as showing how closely two sets of skilled observers have agreed in the photometry of sources differing in color by the amount in question.

MR. R. B. HUSSEY: It seems to me that this paper should mark a distinct step in the progress of the science of illumination. We have for a long time recognized the desirability of a more definite, reasonable standard of light. It was suggested by Dr. Steinmetz several years ago that the primary standard of light should be in some form a measured quantity of radiant energy, but it has remained for the author of this paper to present this in definite, concrete shape, so that now, it becomes a practical thing. The method of heterochromatic photometry and the primary standard belong together. Without a satisfactory method of photometry such a primary standard of light would be impossible.

It seems to me that this is a matter upon which the Society should take some action, at least through its committee on standards and nomenclature, with the idea of establishing an absolute standard of light in this form, or some modification of it.

In regard to Dr. Ives' method of heterochromatic photometry, my personal experience with the flicker photometer has been somewhat limited, but I recall reading an article some time ago by an investigator which stated that with different types of flicker photometers he had obtained different results. I would like to ask what type of photometer Dr. Ives used and if he has ever

found any difference in the results obtained from photometers of different kinds.

Another question I would like to ask is in regard to the range of intensities to be used. Dr. Ives has specified an intensity of 25 meter-candles, and states that the flicker photometer developed an effect opposite to the Purkinje effect. I would like to ask within what range of illumination this effect is not encountered.

Also in regard to the measurement of radiant energy—I wish he would give us a little more detail in regard to the method of measuring the radiant energy of his primary standard.

Mr. H. P. Gage: I should like to say a word in regard to a little different form of illuminating engineering with which I happen to be connected just now. I am connected with a plant which manufactures a great deal of the glass used in signal engineering, the principal colors used being red, yellow, green and blue. These colors, I may say, have been very carefully standardized for railway signal work, so that we have a definite standard for the red, for the green, for the blue and for the yellow, but we do not know what values these have as compared to white light. For example, if we have a white signal light which gives 50 candle-power, we do not yet know what candle-power the light would have if a standard red, or yellow, or green glass were put in front of it, and in railway engineering it would be a very interesting and valuable thing to know what this value is. I think possibly in illuminating engineering it would be of help if these values were known, because these signal glasses are standards which, on account of their commercial value, will be maintained indefinitely. It might be a good thing for the illuminating engineers to have these standards known.

Dr. H. E. Ives: In taking up the question asked by Mr. Hussey in regard to getting different results from different photometers, I would say that the experiments given were carried on entirely with a simple type of flicker photometer in which a certain requirement was postulated as desirable, namely that there should be no dividing line of any sort between the two fields. In the later part of the work, this was achieved by taking a glass plate, coating it with a layer of platinum, cutting the glass from the back and breaking it. The edge of the metal

surface was as close to being infinitely narrow as anything could be. With this photometer, if the two lights were the same color, the speed of the flicker device simply dropped to zero. As the color difference increased, it became necessary to speed up the photometer faster and faster.

As regards getting different results, they are apt to be obtained at considerable differences in illumination, and I think different results might be obtained with the same instrument and different observers or the same observers and a different instrument of different field size. Regarding the magnitude of the Purkinje and similar effects, this, of course, depends upon the difference in color; with, say the carbon and tungsten lamp, I should say one could drop down as low as 3 or 4 meter-candles without being able to pick up differences. If, on the other hand, we are working with bright colors and we place our limit of allowable error at 1 per cent. we might reach that error at 7 or 8 meter-candles. With a small field it would be possible to carry this range much further.

As to the details of measuring radiant energy, I did not go into this because about a year ago Fabry and Bensson made a research into intensity of radiation from the green mercury line corresponding to one candle-power, the results of which were reported in the *Comptes Rendus* and I would recommend that Mr. Hussey read this paper.

A STUDY OF NATURAL AND ARTIFICIAL LIGHT-DISTRIBUTION IN INTERIORS.*

BY M. LUCKIESH.

INTRODUCTION.

The ultimate goal of the illuminating engineer is the production of a system of lighting which will combine high efficiency with good esthetic effect and proper hygienic conditions. Many are wont to go to nature for examples of good lighting led by their belief in the assumption that as the eye has evolved under natural outdoor lighting there will be found in nature that which pleases and yet produces the minimum of eye-strain and resulting physical discomfort. To what extent that assumption is justified is an open question. However, it is of interest to compare natural lighting with the attempts that have been made to imitate it in the design of artificial lighting units and installations and also with those more common installations which make no pretense of imitating nature's lighting.

The distribution of light in nature varies enormously with time and place. Overcast days are quite unanimously considered unpleasant and depressing owing largely to the absence of shadows. Sometimes dark ceilings have been erroneously likened to an overcast sky, when as a matter of fact the latter more nearly resembles the condition of indirect lighting. An overcast sky is nearly always brighter than a deep blue sky and presents a higher brightness than the objects illuminated by it. Overcast days being unquestionably unpleasant, there remains the bright sunny day to be considered. A certain scene in nature will not appear equally pleasant throughout a day. Long and ill-defined shadows seem to be necessary to produce a pleasing effect. In a previous study[1] of the distribution of luminosity in nature this point was very apparent. Another point brought out by that in-

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

[1] Distribution of Luminosity in Nature. Ives & Luckiesh, TRANS. Ill. Eng. Soc., vol. VI, p. 687, Oct. 1911.

vestigation was the fact that the highest brightness for the particularly pleasant scenes was found somewhere in the first 45 deg. above the horizontal. The scene which is pleasant in the early and late portions of the day become depressing and unpleasant at noon when the shadows are small and sharply defined.

On a sunny day about 80 per cent. of the light which reaches the earth comes directly from the sun while the remaining 20 per cent. comes from the sky. In other words 20 per cent. of the outdoor light on a clear day is diffused light. This proportion varies with the clearness of the atmosphere. If one chooses to copy these conditions, but by no means does the writer advocate it, a semi-indirect unit should be employed but the unit must send 80 per cent. of the useful light directly to the working plane leaving 20 per cent. to come via the ceiling and walls. This is not the case with any of the semi-indirect units in use at the present time. In fact, the ratio of diffused light to direct light is more than reversed. A bare unit hung close to the ceiling more nearly approaches nature's lighting under a clear sky with the sun unobstructed than any other system. In a room so lighted short and long shadows will be found. In fact in a room of moderate size lighted by a direct diffusing unit in the center the condition immediately beneath the unit resembles mid-day in nature, while near the walls will be found the longer shadows of the later afternoon. Certain direct lighting units then more nearly approach this condition of nature's lighting than either the indirect or semi-indirect units.

It has been said that indirect lighting goes to the other extreme and reproduces the conditions obtaining on an overcast day. This is not accurately true for the light from the upper walls and ceiling is more or less directed.

While it is well to bear in mind the distribution of light in nature, it will be of interest to compare indoor natural lighting with artificial lighting under various conditions. Several representative rooms were chosen for this purpose and various unusual measurements were made with the hope of obtaining more complete data than are usually furnished by measurements of illumination on a horizontal plane.

Illuminating efficiency is frequently defined as the ratio of the

effective lumens on a horizontal test-plane to the total lumens generated. While this ratio gives the illuminating engineer valuable information it certainly does not measure illuminating efficiency under all conditions. The term "illuminating efficiency" should take into account not only the amount of light which reaches the test plane but also the manner in which that light gets there. The distribution of light flux about a point in space is quite an important matter. The illumination on a small plane area in a certain position at that point may be due to light coming from a point source or it may be due to light reaching the small area from many directions. The useful value of a foot-candle on the plane will differ in the two cases. At least this holds true in many operations for which light is used. While there is disagreement as to the brightness of walls relative to the ceiling there is a general agreement that diffused light is necessary for proper illumination. Of course the degree of diffusion advisable is another open question; however, it should be possible to establish some method of measuring illumination which involves the diffusion factor. Perfect diffusion obtains in an Ulbricht sphere, while the other extreme is produced by a point source of light amid dark surroundings. Perfect diffusion is approached in a room with ceiling, walls, and floor covered with the same light-reflecting material with the direct light screened from the point in question. Illuminating efficiency will be discussed later.

DIFFUSION OF LIGHT.

The question now arises, What is meant by diffusion? The term, diffused light, is very frequently used to define that light which reaches the working plane or point indirectly—via ceiling, walls, etc. The ratio of the indirect to the total light will be termed the *percentage of diffused light*. In determining this factor one is concerned with the nature of the light sources because the direct light must be screened from the photometer. This is easily done with direct units although various results will be obtained depending on the position of the screen relative to the lighting unit and to the photometer. In indirect lighting if only the direct light is screened from the instrument the percentage of diffused light would be 100 per cent. If the secondary sources are considered as emitting direct light (and

the light from the ceiling is more or less directed) then with this light screened off the percentage of diffused light would be very small. This is well illustrated in data to be referred to later. Obviously the position of the screen again influences the results.

It is often desirable to view various sides of an object, hence the distribution of light about the object is of interest. A factor which is a measure of the uniformity of distribution of light through a point in space might be termed the *degree of diffusion* of light at that point. This could be determined by rotating the tube of a Sharp-Millar photometer about the point measuring luminous intensity in all directions. This quantity would be difficult to measure in practise and is not as important as the following one.

A quantity somewhat akin to the foregoing but of greater moment in the practical use of light is the *uniformity of the distribution of illumination* about a point. This can be determined by measuring the illumination with the photometer diffusing glass placed at the point and perpendicular to various directions. It would of course be impractical to measure the illumination in all directions but a compromise can be made by measuring the distribution of illumination in various planes.

Shadows of course are important, being necessary in some cases and annoying in others; but they have not been given much attention in this paper excepting those on the test plane or at the test points. When shadows are sharp the cause is commonly attributed to lack of "diffusion" and this again brings forth the question, What is meant by diffusion? It indicates that there is an undesirable looseness in the use of certain phraseology.

The character of the shadow primarily gives an accurate idea of the character of the light source and an indication of the degree of diffusion at the point in question. The relative brightness of the shadow gives an accurate measure of the *percentage of diffused light* under that particular condition. In fact this factor was determined by measuring the brightness of a diffusing surface in and out of the shadow. To further illustrate these quantities imagine a small object casting a shadow. By the character of the shadow the lighting system is recognized

and by its relative brightness the percentage of diffused light is determined, while the uniformity of illumination on various planes about the object is obtained only by actual measurement of the distribution of illumination about the point in question. A white perfectly diffusing sphere placed at any point would give an accurate representation of the latter quantity by the distribution of brightness on its surface.

DESCRIPTION OF TEST-ROOMS.

In this investigation the general character of natural indoor lighting was studied in comparison with artificial lighting under various conditions. Besides studying the distribution of light in various planes some measurements were made on the distribution of brightness, and the percentage of effective lumens incident on a horizontal test plane. Measurements were made chiefly in three rooms. The dimensions of these rooms and other data are given in fig. 1. Room 1 was on the first floor and was lighted through three windows in the south side of the room. The lower portion of the window was covered with dark curtains. A low three story building was distant about 100 feet (30.48 m.), obstructing the sky up to about 30 deg. above the horizon. A portion of the sky was visible from all stations on the 36 in. (0.914 m.) test plane which was the plane used in all measurements of horizontal illumination. The ceiling was light cream in color; the walls were covered with dark green burlap, and on the floor was a dark green carpet. The reflection coefficients of ceiling, walls and floor were of the order of magnitude of 40 per cent., 10 per cent. and 7 per cent., respectively. The woodwork was dark. By natural light the room was quite pleasant. It was lighted artificially by a four-light fixture with prismatic spheres (containing 25-watt tungsten lamps) in the center of the room, the lighting units being 2 feet, 6 inches (0.762 m.) from the ceiling.

Room 2 was quite different. It was lighted by windows on two sides—two on the east side and one on the north side. On side B was a low one and a half story building about 35 feet (10.668 m.) distant, while the sky was obstructed very little on side A. The ceiling and walls were cream-colored, light green linoleum covered the floor while a wainscoting four feet (1.219

m.) high encircled the room. The reflection coefficient of walls and ceiling was approximately 40 per cent. while that of the floor was 8 per cent. This room was lighted artificially during

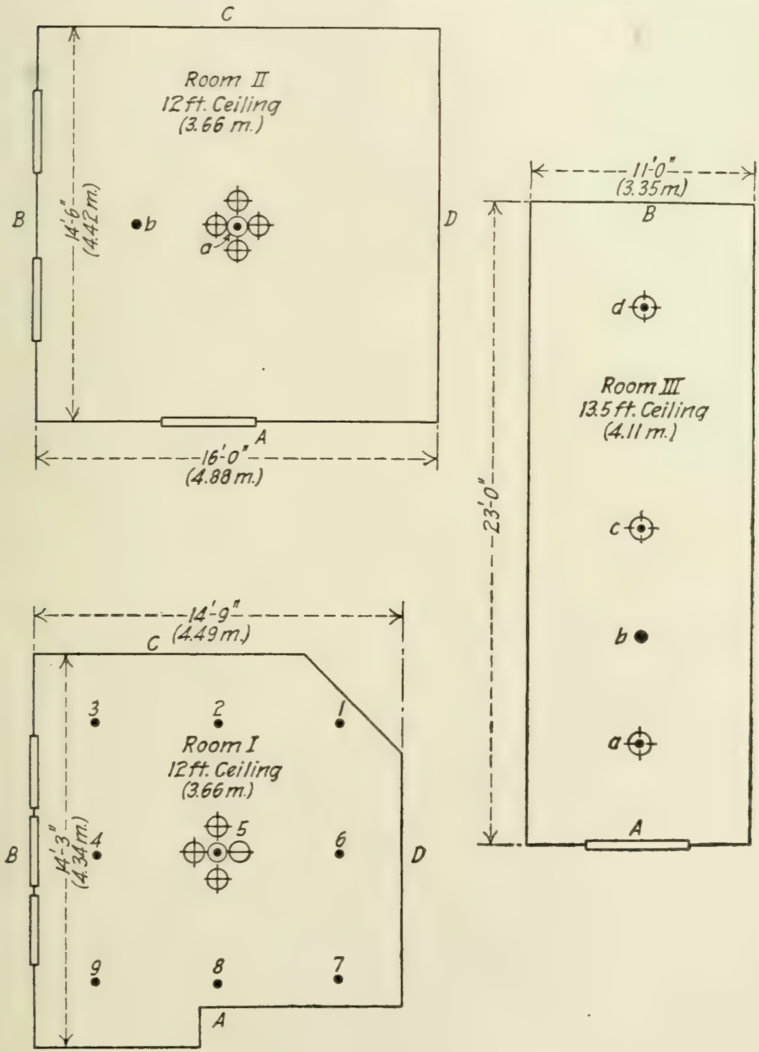


Fig. 1.—Plan of test rooms.

the tests by a four-light fixture with intensive prismatic reflectors containing 40-watt tungsten lamps and also by an indirect unit,

both of the latter fixtures being in the center of the room. Direct light from the indirect unit was incident on the walls to a point about one foot below the ceiling.

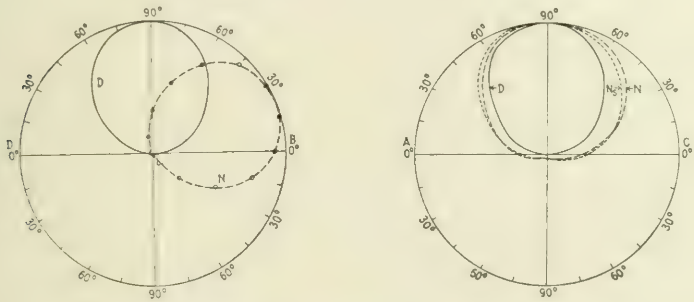
Room 3 was a long, narrow room on the second floor with one large window on one side. The sky was quite unobstructed. The walls were of light-finish wainscoting and the ceiling was white. It was lighted artificially by means of three units which were spaced as shown in fig. 1. These units consisted of 100-watt tungsten lamps in intensive prismatic reflectors.

DISTRIBUTION OF ILLUMINATION IN VERTICAL PLANES.

A Sharp-Millar photometer was used in the usual manner—the light being incident on the diffusing glass plate. The right-angled tube supporting the glass plate was rotated through 360 deg. and measurements of illumination were made every 15 deg. By this means the diffusing glass plate was presented perpendicularly to 24 different directions in a vertical plane. This arrangement did not permit of rotation of the light-receiving glass plate around an axis in its own plane as might have been preferred. Instead it rotated about an axis parallel to its plane and about five inches (12.7 cm.) distant. For daylight measurements very clear or uniformly overcast days were chosen owing to the necessity for constant intensities. In no case did very much direct sunlight enter the rooms during the measurements so that there was no appreciable difference in light-distribution on clear and overcast days. The variable nature of daylight makes it necessary to work rapidly even on days when the intensity seems to be quite constant.

Fig. 2 shows the distribution of illumination about a point in the center of room 1, 36 inches (0.914 m.) from the floor. The vertical plane in this case was BD which intersected the sides B and D. The circles indicate the distribution with the light cream shades drawn. In order to make the interpretation of the polar curves easier it should be explained that any radius-vector represents the relative illumination on the diffusing glass when placed at the origin and perpendicular to the radius-vector and to the plane of the paper. The data throughout the paper is relative. In all cases N indicates natural light while D and I indicate direct and indirect artificial lighting respectively. The

results obtained in the other plane (AC) are shown in fig. 3. As is to be expected, in this case there is a greater uniformity of illumination about a point in a vertical plane with natural lighting than with direct artificial lighting. The distribution of illumination in a vertical plane about the test point has been plotted in all cases with the same maximum and from the curve an idea of the various factors discussed under the foregoing heading can be obtained. An empirical quantity, which will be termed the illumination uniformity factor, will be used to compare the distribution of illumination about a test point in a certain plane for various systems of lighting. The method of obtaining this factor is purely empirical and for lack of a better method



Figs. 2. and 3.—Distribution of illumination in the centre of room I in two different planes. (N indicates natural light, while D and I indicate direct and indirect lighting, respectively.).

it will be considered as the ratio of the mean illumination about a point in one plane to the maximum illumination.

If the small revolving surface on which the illumination is measured is illuminated by a point source the average illumination on the small revolving area will be $\frac{1}{\pi}$ times the maximum. If the test-point receives light in equal quantities from all directions the illumination uniformity factor on the same basis will be unity. Then the lowest value this factor can have is that due to the illumination from a point source which equals 0.3183. The uniformity factors in vertical planes parallel to the walls of the rooms have been determined in this empirical manner and are presented with other data in table 1 which is a summary of the data shown in figs. 2 to 9. (This data will afford a means

of calculating the above factor in several other ways if desired.) The average illumination on the test plate in its 24 positions, when rotated about an axis perpendicular to the plane under consideration is, in terms of the maximum, equal to the so-called illumination uniformity factor. The average illumination in foot-candles can be obtained by multiplying the illumination uniformity factor by the maximum value in foot-candles. The *degree of diffusion* of light at any point in space differs from the factor just discussed in that if the point receives light from a point source the *degree of diffusion* would be zero.

While the adopted method of plotting the distribution of illumination is advantageous in indicating the illumination uniformity factor and the direction of the light, it does not show

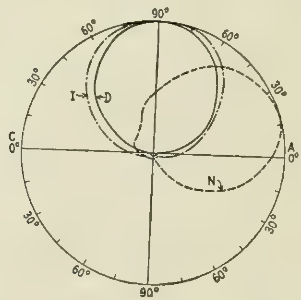


Fig. 4 *a*.—Distribution of illumination in a plane in the centre of room II.

clearly the exact magnitude of various important factors such as upward light and minimum illumination. To give an idea of the relative values of these latter quantities the data in fig. 4a (referred to later) is plotted in a different manner in fig. 4b. Tables 1 and 2, presented later, also give an idea of these values.

The data obtained in room 2 are shown in figs. 4a, 4b, 5 and 6. The uniformity factor is greater with the indirect system than with the direct system, and as was expected, in such a room natural lighting compares favorably with indirect lighting in this respect. Too often it is assumed that natural light indoors is very diffuse when as a matter of fact it is quite directed. Figs. 4a (also 4b) and 5 show the distribution of illumination in the vertical planes BD and AC cutting the sides B and D and A and C, respectively. The photometer test plate was in the center of the room 36 in. (0.914 m.) from the floor. The data shown

in fig. 6 was obtained with the photometer test plate at station b (side center), fig. 1. It will be noted that the areas enclosed by curves D and I have increased at station b while the area of N has decreased. This increase in area of D and I seemed always to be the case for stations nearer the walls. Likewise, there was usually a greater percentage of diffused light near the walls of a room lighted from a central fixture than in the center of the room.

The variation in the distribution of daylight illumination in a vertical plane perpendicular to the window is shown for three stations (a, b, d, fig. 1) in room 3 in fig. 7. N_a represents the condition at the station (a) nearest the window while N_d was obtained at (d) at the extreme end of the room. As would be

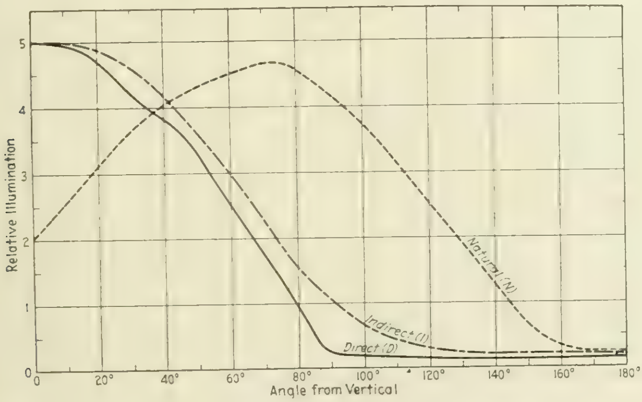
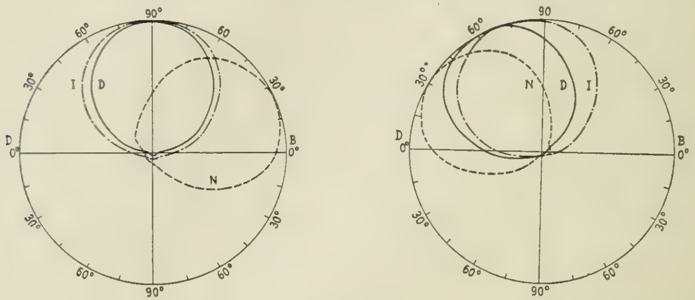


Fig. 4 *b*.—Distribution of natural, direct and indirect illumination in room II.

expected, the general direction of the light is more nearly horizontal as the distance from the window increases. The reflection from the adjacent wall is apparent in N_d. This reflection adds considerable diffused light. In fig. 8 is shown the distribution of direct artificial illumination at three stations (a, b and c, fig. 1). Considerable difference in the area of the curves is apparent. Station b, between the lighting units, shows a more desirable distribution of light than station a, directly under the unit. Station C was in the center of the room. Often it was noted that where the illumination uniformity factor is greater the minimum illumination in a vertical plane is relatively greater than in the cases of smaller uniformity factors.

It was thought desirable to attempt to imitate with artificial light the natural distribution of light in one of the rooms. For



Figs. 5 and 6.—Distribution of illumination in two vertical planes in room II.

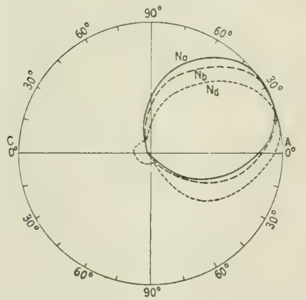


Fig. 7.—Distribution of daylight illumination at three stations in room III.

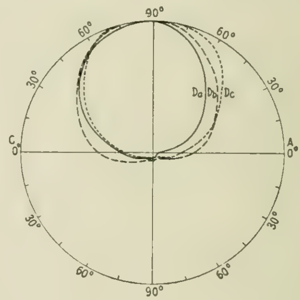


Fig. 8.—Distribution of direct artificial illumination at three stations in room III.

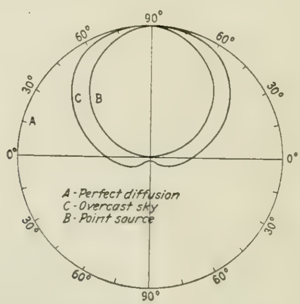


Fig. 9.—Distribution of illumination in a vertical plane about a point under three conditions of lighting.

this purpose room 2 was chosen. Frames covered with diffusely reflecting white cardboard were inserted in the window openings and these were illuminated by means of a specially designed re-

flector held from the wall at the upper part of the dummy window by means of a bracket. The reflectors were so adjusted as to give approximately the same relative distribution of brightness on the imitation window as obtained by natural light. Of course the approach to natural conditions in this respect was only approximate because in natural lighting the distant sky was the principal source of light while in the artificial case the dummy windows became the light sources. Measurements, however, showed the distribution of light in the room to be about the same as obtained under natural lighting conditions. The effect of this arrangement was satisfactory. There was also an indication of the possibility of as high an efficiency being obtained by this method of indirect lighting as by the ordinary overhead indirect systems. Further study along this line is proposed.

ILLUMINATING EFFICIENCY.

It seems that some better method of comparing different systems of illumination should be devised. The percentage of total generated lumens that are "effective" on a horizontal plane does not necessarily measure illuminating efficiency. In other words, one lumen on a small horizontal area probably equals another lumen on the same plane in illuminating value only when the light in the two cases comes to the plane in the same manner. While there are several questions, such as brightness of walls and spectral character of light, involved in the question of illuminating efficiency, the matter of diffusion is of considerable importance. The amount of diffusion necessary for good lighting will perhaps long be a subject for disagreement and may never be exactly expressed mathematically, but it is possible at once to place this value between two limits, namely, no diffusion, as from a point source, and perfect diffusion as obtains in an Ulbricht sphere under proper conditions. In fig. 9 curves are plotted showing the distribution of illumination in a vertical plane about a point under three conditions of lighting. The large circle A represents complete diffusion while curve B shows the distribution of illumination due to a point source. In this latter case the point source was 8 feet (2.438 m.) from the diffusing glass of the photometer and stray light was carefully eliminated. Curve B should be a circle but it is not, owing

chiefly to the fact that the diffusing glass reflects somewhat specularly, and very slightly to the manner of rotation of the diffusing glass. The latter is not rotated about an axis in its plane and hence the angle of incidence of the light is exaggerated. Curve C shows the results obtained on the roof of a high building on an overcast day. The sky was unobstructed above the horizontal plane through the diffusing glass and the roof was very dark, so that little light was reflected from it. The sky was about three times as bright at the zenith as at the horizon. This fact shows that even a greater illumination uniformity factor (indicated roughly by a greater area enclosed by the curve) would be obtained from a uniformly bright hemisphere. The areas of all the curves are given in table I. It will be noted in

TABLE I—SUMMARY FOR FIGS. 2 AND 9.

Fig.	Curve	Maximum foot-candles	Minimum foot-candles	Average foot-candles	$\frac{\text{Min. f. c.}}{\text{Max. f. c.}}$ per cent.	Illumination uniformity Factor $\left(\frac{\text{Aver. f. c.}}{\text{Max. f. c.}}\right)$	Relative areas enclosed by polar curves
2	D	2.2	0.07	0.72	3.4	0.326	61.0
	N	46.3	0.03	15.3	1.0	0.331	65.5
3	D	2.2	0.08	0.71	3.4	0.323	60.8
	N	21.7	0.50	7.8	2.3	0.359	80.0
	N_s	2.9	0 07	1.04	—	0.360	80.6
4a	D	4.9	0.12	1.60	2.5	0.327	64.0
	I	2.8	0.11	0.98	3.8	0.350	75.0
	N	29.6	0.84	10.53	2.8	0.356	74.3
5	D	4.9	0.12	1.62	2.5	0.330	64.0
	I	2.8	0.11	0.98	3.8	0.351	74.6
	N	22.0	1.2	7.74	5.5	0.352	68.5
6	D	3.6	0.10	1.22	2.8	0 340	67.5
	I	2.1	0.06	0.73	3.0	0.357	76.5
	N	20.0	1.0	6.8	5.0	0.340	64.3
7	N_a	227.0	3.9	74.75	1.7	0.329	64.0
	N_b	82.0	0.83	26.86	1.0	0.328	61.0
	N_d	22.7	2.0	7.8	9.0	0.343	63.0
8	D_a	2.8	0.14	0.96	5.0	0.344	69.0
	D_b	2.2	0.16	0.83	7.3	0.376	82.5
	D_c	3.1	0.18	1.10	6.0	0.358	78.5
9	A	—	—	—	100.0	1.000	276.5
	B	—	—	—	0.0	0.318	59.5
	C	—	–	—	—	0.381	90.0

some cases that the daylight curves enclose a smaller area than the direct artificial light curves. Indirect lighting showed the

greatest illumination uniformity factor in all cases tested except in the case of a distributed system of direct lighting. In room 3 it will be noted that the latter system shows a very much greater uniformity factor than daylight from a single large window.

EFFECTIVE LUMENS ON A HORIZONTAL TEST-PLANE.

Owing to the manner in which daylight enters a room through the windows it is of interest to determine the percentage of effective lumens incident on the working plane. On account of the fact that none of the light which directly reaches the test-plane strikes it normally a high efficiency in this respect is not expected. Some of the light which enters the room strikes the walls and floor and is reflected and re-reflected before it finally reaches the plane. A study of the data obtained reveals the fact that the percentage of diffused daylight in interiors is of about the same order of magnitude as the diffused light under artificial lighting conditions. The method of obtaining the percentage of effective lumens on a horizontal plane was to determine the total lumens entering the room and the total lumens incident on the working plane.

Let A_1, A_2, A_3, etc., = area of the windows respectively in square feet.

E_1, E_2, E_3, etc., = average illumination in foot-candles on the plane of the respective windows.

E' = average illumination in foot-candles on the horizontal test plane.

A' = area of test plane in square feet.

Then

$$\frac{A'E'}{A_1E_1 + A_2E_2 + A_3E_3 + \text{etc.}} \times 100 = \text{per cent. ``effective''}$$

lumens on a horizontal plane.

The average illumination on the window was determined both by means of the Sharp-Millar photometer and a special arrangement of a diffusing glass and mirrors. This arrangement consisted of an elbow tube of 8 in. (20.32 cm.) square cross-section with a diffusing glass in one end and a mirror in the angle of the elbow. The end containing the diffusing glass was placed against the window pane and its image was reflected downward

by the mirror. The brightness was measured with a photometer in its natural position and the mean illumination on the window was determined. Room 1 with dark walls and with windows only on one side, had 17 per cent. of the total lumens entering the room incident on a horizontal plane 36 in. (0.914 m.) from the floor.

Room 2 with light walls and with windows on two sides showed 33 per cent. of the total entering lumens to be incident on the test plane. With the direct lighting system the lumens on the same test plane in room 1 amounted to 30 per cent. of the total generated, and 35 per cent. in room 2.

SOME COMPARATIVE RESULTS IN THE THREE ROOMS.

In Table II are shown various data which give some idea of the distribution of light under various conditions. The ratio

TABLE II—COMPARATIVE ILLUMINATION RESULTS IN THE THREE ROOMS.

Room	Station	Lighting	Per cent. diffused light ($I_s I_h$) Per cent.	Ratio of Max. on vertical planes to I_h Per cent.	Ratio of $\frac{Min}{Max}$ on four vertical planes Per cent.	Ratio of upward to downward Illumination Per cent.
		D	6.0	9.3	40.0	3.4
I	5	N	2.2	215.0	7.5	4.7
	(Center)	N(Shades)	27.8	240.0	6.7	10.0
		D	15.8	58.0	6.8	2.4
I	6	N	2.4	183.0	7.9	5.1
	(Side center)	N(Shades)	20.0	333.0	10.0	—
		D	5.7	3.6	80.0	2.5
II	Center	I	6.2	17.5	86.0	3.8
		N	5.5	207.0	5.3	8.5
		D	14.0	50.0	16.2	6.2
II	Side center	I	—	34.5	43.0	3.0
		N	33.7	183.5	6.6	6.4
III	a	D	5.8	23.5	16.4	5.0
		N	2.3	192.0	2.6	5.7
III	b	D	5.4	43.0	14.9	7.3
		N	8.0	278.0	2.8	15.2
III	c	D	17.9	26.6	79.0	6.0
		N	13.7	—	—	—
III	d	D	5.5	22.0	21.0	5.8
		N	24.7	388.0	8.4	33.3

of the brightness of a shadow cast upon a diffusing surface to the brightness of the surface under the total direct and reflected light was determined at various stations. This factor I_s was actually obtained by casting a shadow which just covered the diffusing plate of the photometer. The object which cast the shadow was of constant size but its distance from the diffusing glass varied. It is evident that the percentage of diffused light as measured in this manner varies with the distance of the object which cast the shadow. This value $\frac{I_s}{I_H}$ (I_H = illumination on a horizontal plane outside the shadow) is a correct value of the percentage of diffused light *only* for that particular condition under which it was obtained. To obtain the true value, or more nearly so, the direct light should be screened nearer the light-source. Obviously this would be difficult and impracticable with indirect or natural indoor lighting. Attention is again directed to the distinction between diffused light as used here on a horizontal plane and degree of diffusion about a point as defined in the first part of the paper. The percentage of diffused light under artificial conditions as obtained by the above method compares favorably with that under daylight illumination. With direct lighting the shadows become relatively less dark near the walls of the room when the latter is lighted from a central unit. This would not be as marked when the illumination of the test plane is quite uniform. The true or maximum percentage of diffused light is more nearly a constant value throughout a horizontal test plane. In room 3 the percentage of diffused light rapidly increases with the distance from the window for natural lighting.

Illumination measurements were made with the test plate 36 inches (0.914 m.) from the floor and parallel to the walls. The ratio of the maximum of these four readings to the illumination on a horizontal plane is shown in the next column. The figures illustrate a great difference in interior lighting by natural and artificial methods. The next column shows the variation in illumination on the four vertical planes just described. Natural lighting is inferior in uniformity in this respect and indirect lighting shows the greatest uniformity. As is well recognized,

extended sources produce less annoying shadows in most cases but it must not be supposed that extended sources such as a patch of sky through a window do not give fairly sharp shadows under many conditions. Another reason for the use of extended light sources of low brightness is found in the elimination of glare from objects such as polished metal and especially glazed paper.[2]

The ratio of upward to downward light was determined by pointing the photometer tube with diffusing plate first downward and then upward measuring the illumination in each case.

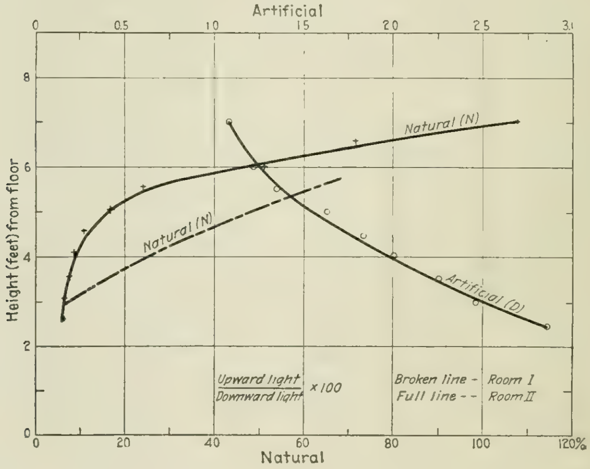


Fig. 10.—Ratios of upward and downward light with natural and artificial lighting obtained in the centre of rooms I and II.

This ratio is of little or no importance in such a case as desk lighting, but it becomes of greater moment in many industrial operations. While no elaborate study of this feature has been attempted some data will be presented which will further illustrate the great difference in the distribution of light under natural and artificial interior lighting conditions. In table II is shown the ratio of upward to downward illumination at various stations, the test plate being 36 inches (0.914 m.) from the floor. With artificial systems the upward light is but a few per cent. of the downward light while this ratio is much greater with

2 M. Luckiesh, "An Analysis of Glare from Paper," *Elec. Rev.*, June 1, 1912.

natural lighting as is evident from the curves in fig. 10 which were obtained in the center of rooms 1 and 2. It is evident that the height of the test plane, area of sky exposed, reflection from the ground, buildings, and especially from snow, affect this ratio. Under practical conditions this ratio for natural lighting will nearly always be much greater than that for artificial lighting. This should be of considerable importance in many cases, especially in industrial lighting. From table II it will be noted that this ratio increases steadily for natural lighting as the distance from the window in room 3 is increased.

DISTRIBUTION OF BRIGHTNESS.

From both the esthetic and hygienic standpoints the distribution of brightness is of considerable importance. In a previous

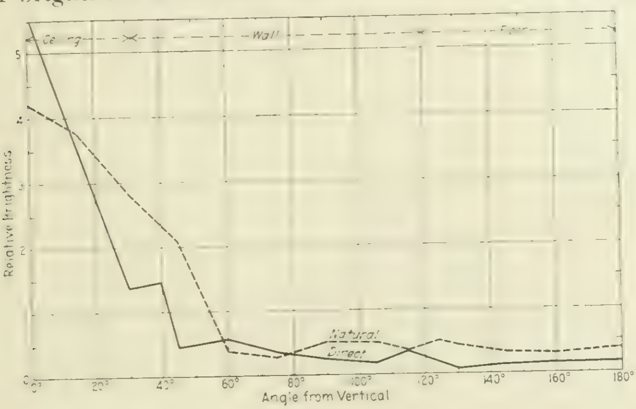


Fig. 11.—Results of brightness readings taken in a plane (room I) parallel to the window with direct and natural lighting.

study[3] it was found that for pleasant conditions the brightest point in the field of vision was somewhat above the horizontal. While there is no unanimous agreement as to the relative effects of light and dark walls on fatigue and eye-strain, it may prove of interest to show the distribution of brightness under natural and artificial lighting in two rooms—one with light walls and the other with dark walls. In both cases the reflection coefficients of the ceilings were of the same value. The brightness readings were made with the illuminometer with the diffusing glass removed.

[3] Loc. cit.

In room 1 with dark walls and floor the brightness readings were taken in a vertical plane AC parallel to the window. In fig. 11 are plotted the results with direct and natural lighting. The abscissae represent angles between the vertical and the axis of the photometer tube, which was in the center of the room 36 inches (0.914 m.) from the floor. In spite of the difference in direction of the natural and direct artificial light there is a close resemblance in the brightness distribution in the two cases.

The results obtained in room 2, plane AC, are shown in fig. 12. It will be remembered that this room had a light ceiling, and walls with windows on two sides. Here again there is a striking resemblance between natural and direct artificial in-

Fig. 12.—Results of brightness readings taken in room II with direct and natural lighting.

terior lighting. The brightest area in the room under natural lighting conditions is on the side walls near the horizontal line of vision. This is generally true with light colored walls illuminated by daylight through windows. This fact is worthy of the attention of those who condemn light walls.

In the foregoing measurements of brightness the light sources were left out of account assuming that in a properly lighted room no brilliant sources would be permitted in the field of vision Of course the brightness of the sky and the artificial lighting units employed are usually many times greater than the surfaces which they illuminate and could be plotted on no reasonable scale with the other data. It might be possible that

the light sources even though out of the range of normal vision play an important part physiologically and psychologically.

While on the subject of brightness it might be well to call attention to the relative brightness of objects commonly associated. The following values are only roughly approximate:

$$\frac{\text{Sun at zenith}}{\text{Blue sky}} = 300{,}000,$$

$$\frac{\text{Sun at 5 deg.}}{\text{Blue sky}} = 1{,}000,$$

$$\frac{\text{Sun at zenith}}{\text{Bright cloud}} = 30{,}000,$$

$$\frac{\text{Bright cloud}}{\text{Blue sky}} = 10,$$

$$\frac{\text{Tungsten filament}}{\text{Bright ceiling}} = 150{,}000,$$

$$\frac{\text{Frosted tungsten lamp}}{\text{Bright ceiling}} = 500,$$

$$\frac{\text{Overcast sky}}{\text{Brightest object in room}} = 10.$$

CONCLUSIONS.

While the rooms studied were representative of general types not many conclusions will be drawn. The writer prefers to present most of the results of the investigation merely as data to be interpreted by the reader as he sees fit. A few conclusions, however, appear justifiable.

The measurement of illumination on a horizontal plane does not give a fair comparison of illuminating efficiencies. The distribution of illumination in various planes is of considerable importance when comparing various systems of lighting. A careful distinction is made between the percentage of diffused light and the degree of diffusion of light about a point.

The areas enclosed by the polar curves of illumination distribution in a certain plane roughly indicate the uniformity of illumination in that plane about the test point. When these curves are plotted to the same maxima a rough comparison of these uniformity factors can be made. An empirical method of calculating this factor has been used but the author realizing

that this is merely a matter of opinion has presented the data in table 1 from which it is possible to make calculations on a different basis if desirable.

The uniformity of the distribution of light about a point under natural lighting conditions in interiors is not as great as is sometimes assumed and is often less than that obtained by direct or indirect lighting. Unless the room has windows on more than two sides it is likely that indirect lighting will always show a greater degree of diffusion and a greater illumination uniformity factor about a point than natural interior lighting.

While extended sources assist in diffusing light, even a greater illumination uniformity factor is obtainable by a distributed direct system. Extended sources are advantageous in eliminating sharp shadows and glare from glazed paper and polished objects.

The great difference in the ratio of upward to downward light for natural and artificial lighting may partly account for the greater desirability of the former in many cases, especially in industrial lighting.

Daylight entering a room through windows is to a considerable extent incident upon the walls producing a distribution of brightness more nearly that obtained by direct artificial lighting. At least this result was obtained in rooms of extreme types and other observations indicate this similarity to be somewhat general. Attention is directed to the fact that in rooms with light walls the brightest spot in the room under daylight illumination is usually on the wall near the horizontal line of sight.

It is possible to artificially imitate the distribution of daylight in a room with pleasing effect and with an efficiency not prohibitively low.

While more or less general information has been obtained from the investigation much of it is difficult to transmit. The work was undertaken with the view of making a general analysis of the distribution of light in ordinary rooms under usual lighting conditions.

The writer wishes to express his thanks to Mr. Leonard Krill for his valuable assistance in the measurements.

DISCUSSION.

MR. J. R. CRAVATH: The practical application of such investigation as this naturally falls along two lines: first, as related to artistic effect, and second, as related to comfortable working conditions. In the matter of artistic effect there may be differences of opinion. Therefore, it is very difficult to apply results of this kind to the artistic side. I will not attempt to do it to any great extent. I should like, however, to question one statement made on the first page, *viz.*, "Overcast days are quite unanimously considered unpleasant and depressing, owing largely to the absence of shadows." We will all agree that such days are depressing, but the reason therefor has not yet been established.

I agree fully with everything Mr. Luckiesh says regarding the importance of diffusion and direction of light as received at any given point. I have made a few experiments along somewhat similar lines to his to determine whether it was possible to get up specifications which would cover satisfactory illumination. I had in view the possibility of drawing up specifications which would enable the engineer to specify for whomever is buying the illumination, what the distribution should be in order to produce freedom from glare on paper in the office or elsewhere. I used the same method which Mr. Luckiesh has described here and got somewhat similar shapes of distribution curves. The method does not tell anything that is particularly useful along that line, however, for the reason that the photometer has a diffusing plate and, therefore the curve of light distribution is essentially a curve of diffused light and this did not show what I wanted to determine. For example, if the photometer is used where a considerable percentage of the light comes from one particular point, photometer readings through a diffusing glass test plate are not an indication of the amount of annoying glare you may get from paper with any given system or arrangement of lights.

MR. F. A. VAUGHN: It is desirable to emphasize two points brought out by a previous speaker; that is, the subjects of diffusion and the undesirability of the imitation of daylight as found in interiors. However, relative to the latter point, I should like to state that there is one more quality which daylight possesses, one which will be very difficult to overcome in our campaign of

education, or to imitate, and that is the cheapness of it. Central station managers will find some difficulty in reaching the pace set by daylight in this regard.

It is not necessary to dwell upon the desirability of diffusion, because that will be well covered in the forthcoming papers, as it has been already in those which have been presented.

A question arises, relative to the tables on the twentieth page of the paper, as to just what is meant by "bright ceiling" and whether the first is the same as the second bright ceiling, and also why the ratio was not carried on in the last item.

MR. M. LUCKIESH: In reply to Mr. Cravath's statement, I would say that when one gets away from the measurement of foot-candles on a horizontal plane, he gets into an unexplored wilderness in which I would not hope in the first investigation to get data which would lead to specifying what does constitute proper distribution of light in a room. The object of the paper was merely to analyze conditions as they were found and getting a start toward defining what good illumination is.

In regard to Mr. Cravath's statement about measuring the distribution about a point by the use of a diffusing plate, there are only two possible screens which could have been used; one would be a diffusing plate and the other a mirror. In any investigation one should use apparatus which could be defined; and one reason for using the diffusing plate is that one would probably get nowhere if he used a mirror; another reason is that one sees an object by diffused reflection.

There has not been enough work done on this subject; it is a case on which the available data is yet inadequate; and one can only express his personal opinions. I surely admit that daylight, as found in the average room, and especially right here, is very bad; but there are cases where daylight distribution can be used with good artistic effect. There is no good reason to believe that there is not a place for everything and I attempted to imitate the distribution of daylight with artificial light just to see what came of it. I think the whole paper shows the possibility of improving by artificial distribution upon the daylight distribution.

In regard to Mr. Vaughn's remarks concerning the figures on the twentieth page of the paper, I will say that the "bright ceiling" is one actually measured in one of the rooms. The ratios are presented merely to show their order of magnitude. For instance the ratio of the brightness of the sky to the brightest object in the room would be about ten for this particular case.

A NEW METHOD AND AN INSTRUMENT FOR DETERMINING THE REFLECTING POWER OF OPAQUE BODIES.*

BY P. G. NUTTING.

The reflecting powers of diffusely reflecting opaque bodies have heretofore been determined, so far as the writer is aware, only by indirect or laborious methods involving calculations or integrations and very considerable systematic errors. The method here described was proposed and used by the author in official tests early in 1911. Recently (May, 1912) several improvements were introduced, a specially designed precision instrument constructed and its sensibility and residual errors investigated.

The principle of the method is that of two parallel infinite planes, one of which is a diffuse illuminator and the other the surface whose reflecting power is to be determined. The relative brightness of the two planes is then the reflecting power of the non-luminous plane. The luminous plane may be a transmission screen provided it be non-selective as regards direction, wave-length and polarization of the transmitted light.

The practical application of this method requires the possibility of (1) using planes of limited (rather small) area and (2) of determining the relative brightness of the two planes without sensibly disturbing the light distribution.

The planes were limited in the first design by a wooden frame lined with white paper about 20 cm. square, separating the two planes about 30 mm. This gave satisfactory readings but was later replaced, chiefly for mechanical reasons, by a brass ring heavily nickel plated and highly polished. Into this ring is inserted the modified Martens-König polarization photometer used to determine the relative brightness of the two planes at the center of the ring.

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

Fig. 1 shows a plan and an optical diagram of the reflectometer; the photographs (figs. 2 and 3 show it as mounted on its stand in use. The ring is 150 mm. in diameter and 32 mm. wide with a side tube to admit the nose of the photometer. The photometer is one of the ordinary Martens-König photometers with specially cut (21 deg., 1.52) glass wedges placed over the nose piece holes. These increase the angle of the entering beam to about 75 deg.; 90 deg. prisms do not allow sufficient diffusion

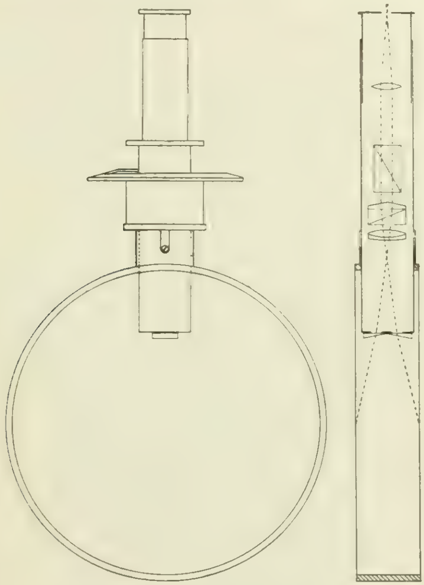


Fig. 1.—Plan of the reflectometer.

of light, while with no prisms at all the light is received at too nearly grazing incidence.

The stand is simply a rack on which is placed first the card or other surface whose reflecting power is to be determined, then the ring, then the diffusing screen. This screen is a sheet of dense milk glass or porcelain rough ground on both sides. Even ordinary paper, if uncalandered and free from water marks will serve the purpose. Clear glass, even when ground on both sides, does not give correct results, probably on account of the increased percentage of normal transmission.

Readings are taken in four positions; in two quadrants with photometer direct, then in the same two quadrants with photometer reversed, thus eliminating the error of scale zero and determining the residual polarization. A screw head on the photometer engaging a slot on either side of the neck of the ring permits the ready reversal of the photometer.

The photometer circle is divided into single degrees. Successive settings agree usually to one or two-tenths of a division. The uncertainty in a set of five readings is not over half a tenth or 3 minutes of the arc. The relative intensities of the entering

Fig. 2.—Front view of the reflectometer mounted in position.

beams are proportional to the square of the tangent of the angle indicated. The reflecting power is half the sum of those determined in the two principal azimuths.

Other forms of photometers might be used but a reversible polarization photometer is preferable. Polarization amounting to 5 to 10 per cent. is the ordinary case in diffuse reflection and precision is to be attained by recognizing and determining the polarization.

The Martens-König design is admirably adapted for the pur-

pose. The Wollaston prism gives a comparison between plane polarized light of one principal azimuth in one beam with that of the other principal azimuth in the other beam. Let S and X

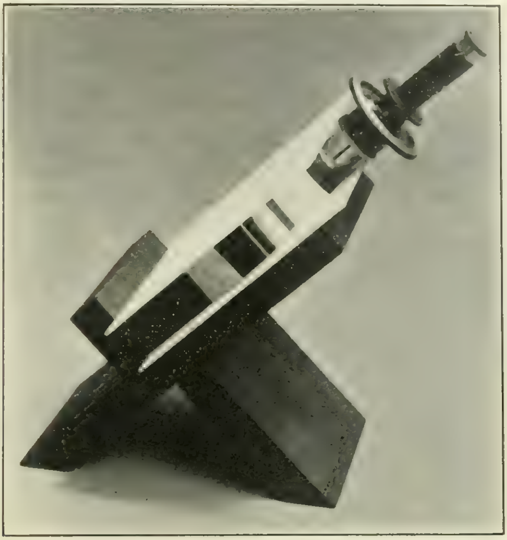


Fig. 3.—Side view of the reflectometer in position.

refer to light from the diffusing screen and unknown surface respectively. Then

$$\frac{S_\perp}{X_\parallel} = R_1 \qquad \frac{S_\parallel}{X_\perp} = R_2.$$

Now

$$\frac{S_\perp}{X_\perp} + \frac{S_\parallel}{X_\parallel} = \frac{S_\perp}{X_\parallel} + \frac{S_\parallel}{X_\perp} - e,$$

where e is a small quantity of lower order in all cases except when both $X_\perp$ and $X_\parallel$ are small and their ratio is large. This is the case of a surface of low reflecting power and high polarization, such as glossy black paper. Hence in all ordinary cases the reflecting power

$$R = \tfrac{1}{2}R_1 + \tfrac{1}{2}R_2$$

directly. In the special case mentioned it is best to compare the black surface directly with white paper or magnesia without using the ring.

The instrument was designed primarily for determining the absolute coefficients of reflection of reference standards, with which other surfaces may be readily compared but it is convenient for many of the ordinary rough determinations as well. For example by covering the diffusing screen by a color filter, the reflecting power may be found for any selected color. For wall coverings with their varied properties, this instrument probably gives a better mean value than any other except perhaps the integrating sphere and much more convenient. It is also serviceable for determining mean transmission coefficients in certain cases.

A sample set of readings is given below. The surface was that of a ground porcelain reference standard.

	Photometer direct		Photometer reversed	
	Deg.	Deg.	Deg.	Deg.
	47.8	132.1	41.1	139.0
	8.0	2.2	1.2	8.8
	7.8	2.1	1.1	9.0
	7.7	2.4	1.1	8.9
	7.9	2.2	1.1	8.8
Means...	47.84	132.20	41.12	138.90
		= 47.80		= 41.10

$$\cot^2 47.82 = 0.8212 = R_1$$
$$\tan^2 41.11 = 0.7619 = R_2$$

0.791 **Reflecting power.**

The correction to the zero is very small (mean $0^\circ.03$), the residual polarization about 3 per cent.

A few readings taken on various substances are given below as samples of the work done.

	R_1	R_2	R	Per cent. polarization
1. Boric acid powder, pressed mat....	0.904	0.824	0.864	4
2. White bond paper	0.793	0.714	0.753	4
3. Ordinary white paper, single sheet over black	0.755	0.689	0.722	4
4. Same, several sheets thick	0.766	0.699	0.733	5
5. Gray circular cover, with nap.....	0.418	0.417	0.417	—
6. Same across nap..................	0.425	0.416	0.421	—
7. Black card.......................	0.060	0.105	0.082	27
8. Black velvet	0.012	0.023	0.018	30
9. 5 repeated after one week by different observer	0.418	0.418	0.418	—

The instrument may be used in the interior of a room or in full sunlight direct or oblique without variation in the reading. The chief sources of error to be guarded against are dirt on the diffusing screen and shadows falling upon it from nearby objects.

The writer is indebted to Mr. Lloyd Jones for able assistance in testing out the instrument.

This reflectometer or, properly, albedometer, promises to fill a want long felt by illuminating engineers. The design has been turned over to Schmidt and Haensch, makers of the Martens-König photometer.

DISCUSSION.

Dr. C. H. Sharp: We can derive from the paper a clearer conception of what is possible from diffusing media and a better notion of the exact mechanism of diffusion. The theoretical part is particularly valuable, as indicating the limitations of diffusion obtainable in this class of material.

Mr. C. O. Bond: The only suggestion that I have to make is one looking toward the more practical use of this instrument. Often the surfaces whose reflection one wishes to measure cannot be detached. Would it be possible to arrange the instrument so that it could be applied to the walls or ceiling and the telescope attachment so turned as to be then used? On this, it seems to me, will depend any very extensive use of the instrument, by illuminating engineers.

Mr. Loyd Jones: In regard to Mr. Bond's question, I would say that there is no reason why the instrument cannot be adapted for use in any position. If necessary the diameter and thickness of the ring could be increased, allowing sufficient space for the photometer to be inserted directly in the side when the ring is in contact with a wall or other extended surface; or an optical means could be provided for changing the direction of the eye-piece relative to the instrument.

As to the lighting of the transmitting screen, it is only necessary that the illumination on the screen be uniform. The angle at which the light falls on the screen is immaterial.

The angle at which the light enters the photometer is determined by the angle of the prisms placed over the nose-piece.

This angle must be such that the light entering the photometer shall come from points on the test surface and diffusing screen that lie near the axis of the ring.

This instrument was designed primarily for the determination of the absolute diffuse reflection coefficients of reference standards in the laboratory—such standardized surfaces to be used as standards in field work by some comparative method.

In some cases, for instance a black glossy paper, where the polarization is high, the error in the result is no longer negligible as it amounts to 3 or 4 per cent.; but as long as the polarization is less than 10 per cent., the error in the reflection coefficient will be less than 1 per cent. The amount of polarization can be calculated from a set of readings and thus the accuracy of the result determined.

CHARACTERISTICS AND TESTS OF CARBONS FOR ENCLOSED FLAME ARC LAMPS.*

BY ALLEN T. BALDWIN AND RICHARD B. CHILLAS, JR.

The advent of the enclosed flame arc lamps and solid or impregnated carbons necessitated the selection of adequate testing methods for commercial carbons. It is desired to make this paper of use to the owners in the operation of their lamps, and of interest to the illuminating engineers so that they may better understand the conditions which must be fulfilled to obtain the desired results. The essential characteristics of the carbons are here indicated, as are tests which will serve as a measure to determine them. This field is of such size as to limit a first paper to a general consideration of its important phases, leaving detailed discussion until a later time.

It was desired to obtain the efficiency of the open flame arc in a lamp giving a greater electrode life. The best method to accomplish this was to decrease the burning rate of the carbons by enclosing the arc. The problem of securing a suitable enclosure was accompanied by many others of equal importance. A method for the removal of the dense white fumes from the region of the arc became necessary to prevent loss of light. Associated with this was the design of the economizer and the distribution of deposit on it. Axially placed carbons in vertical positions were used to obtain a desirable light distribution. This required a study of ways to protect the arc from undesirable magnetic and draft influences. Since increased trim life was to be obtained by enclosing the arc, the constancy of this enclosure and its uniformity from trim to trim were vital.

One point that should be carefully considered in the further development of new lamps is the desirability of standardizing the size of carbons used, particularly the diameter. Variations from this standard should be in length as required to meet the different classes of service, as alternating current or direct

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

current, positive upper or lower, focusing or non-focusing lamps. Such a standard will be generally beneficial since it will simplify the manufacturing processes and will give the user of large numbers of lamps carbons that will be interchangeable in different lamps for the same service.

Solid uniformly impregnated carbons were developed to overcome the unsteadiness of the light that occurs with cored carbons when the arc moves from the area containing the flaming material to one of pure carbon.

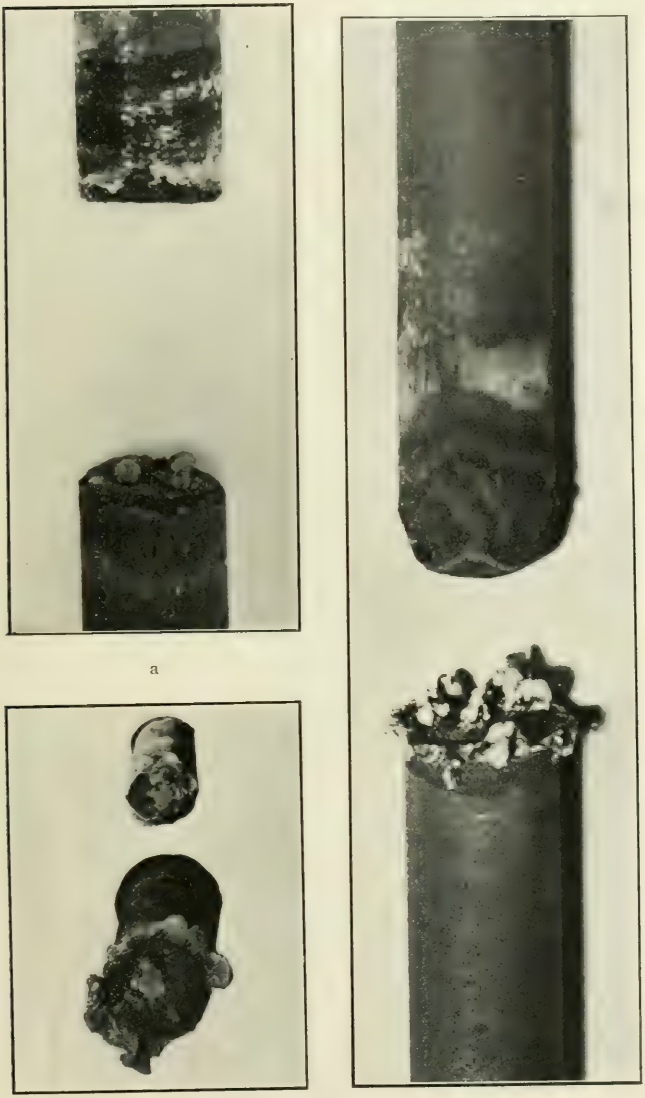
This development has been toward certain ideal characteristics which are essential. We base our tests upon such an ideal carbon, placing importance upon these characteristics much in the following order: (1) reliability in operation, (2) steadiness in operation, (3) life, (4) color, (5) efficiency. Different classes of service influence the order of importance of the last three characteristics so that the sequence given here cannot be considered rigid. Several of these properties are opposed to one another so that the commercial carbon must, of necessity, be designed to yield the best compromise among them.

Reliability in Operation.—The first essential characteristic of the flame carbon is reliability in operation. The greatest factor operating against reliability is slag. Error in the adjustment of the carbons in the lamps is the other cause of irregular operation in so far as the carbons are concerned.

A slag is composed of flame material[1] which collects in a fused state in any position about the carbon points. This slag is non-conducting when cold; consequently, it may interfere with the establishment of the arc or maintenance of the circuit, causing "slag outage." These fused slags take well defined forms which are due mainly to the nature of the materials used and to the conditions under which the carbons are burned. They are named according to their shape and position,—beads, trees and rims, illustrations of which are shown in fig. 1. It is possible for all or for any one or more forms of slag to occur with the same trim of carbons.

A consideration of the factors causing a slag to form will make testing more valuable, since the tests will serve their greatest

[1] Flame material is the name given the chemical compounds used in the carbons to produce the so-called flame arc.



a

b

c

Fig. 1.—Formation on flame carbon electrodes: (a) Three beads prevent upper carbon from coming in contact with the lower one. (b) Two flattened beads of slag prevent contact of carbons; the rim slag on either carbon is not in a position to cause outage. (c) Tree shaped slags on lower carbon prevents contact of carbons.

value when they record the occurrence of the slag and afford some clue as to the cause of formation. The current should be adjusted properly since at low current the energy available is insufficient to volatilize all the flame material present and slag tends to form. Voltage variation throughout the ordinary ranges does not seem to influence the slagging tendency. Poor enclosure of the arc due to chipped or poorly seated globes will increase the rate of carbon consumption, leaving an excess of flame material in a position to form a slag.

Unreliable operation may be brought about by causes other

Fig. 2.—Economizer slag. A column of used material extends from the economizer to the lower carbon preventing movement of this carbon.

than the carbons themselves. The economizer is placed in the lamps to decrease the burning rate of the upper carbon. Situated just above the arc it receives considerable deposit from the ascending dust laden gases. This deposit may become fused and collect in a position where it will obstruct the carbon passage. Fig. 2 is a good illustration of this condition. Magnetic forces exert a very considerable influence on the long flame arc, so it is necessary in axis lamps that the arc should be situated in a nearly neutral or symmetrical field. When directive forces are present the arc remains at one side of the carbons, producing, in time, side burned carbons and slag. (See fig. 3.) Care must be taken to see that all carbon passages are unobstructed, and that the carbons are securely held in proper alignment.

Steadiness in Operation.—When the variations are not readily noticeable to the eye a light may be considered steady. Changes

in the amount and composition of the vapors in the arc produce unsteadiness. The following conditions exert an influence on the steadiness of the arc and the light. The candle-power of the flame arc increases both with its cross-section or current and with its length or voltage. The type of lamp for different electrical

Fig. 3.—This slag formation shown here prevented the carbons from touching and caused "slag outage".

conditions, that is, alternating current or direct current, series or multiple, and the position of the direct current positive carbon possess different degrees of steadiness. In general, the series lamps are steadier than the multiple lamps. In the latter, due to the nature of the arc, steadiness is obtained at the cost of the power absorbed by the choke coil or resistance in series with the arc. Consequently the least amount of ballast, consistent with practical freedom of the arc from rupturing, is used in order to hold the efficiency as high as possible. Differences in the inertia of the moving parts of different lamps of the same type regulate in a somewhat different manner and affect the steadiness.

Unsteadiness of the arc appears to the eye as rupturing, flickering and fading. These features are partly dependent upon one another. Rupturing is breaking of the arc and occurs almost entirely in multiple lamps for reasons given in the preceding paragraph. Increasing the arc voltage increases rupturing. Faulty circulation or drafts produced by the shape of the points, magnetic blow from current carrying parts of the lamp, or variations in the flame material tend to produce arc ruptures. Flickering and fading are best described as fluctuations in the light; the former consists of rapid changes; the latter of slower variations that last several seconds or more. Flickering may be due to flashes of flame material in the arc, to changes in the light flux with fluctuations in current or voltage, or occasionally to a very rapid movement of the arc spots over the surface of the carbons. These movements must not be confused with the slow necessary wandering of the arc over the entire face of the carbons. Fading may be due to changes in the flame material present at the arc caused by variation in the rate of consumption of the carbon. It makes itself apparent as comparatively slow changes in the average candle-power or changes in the color of the light.

Life.—The increase in burning life of a trim of carbons, as the first object to be accomplished by enclosing the arc, has assumed an importance following that of reliability and steadiness in operation because it has been seen that a trim life of convenient length can readily be obtained. The life of a trim of carbons is the number of hours required to burn the carbons to the length at which they cannot come together for the purpose of starting an arc, the current, voltage and enclosure being normal. A difference in the trim life will be obtained between tests conducted on lamps operating intermittently or continuously. The service life should be based on the average trim life.

Aside from the record of possible burning hours attainable, the trim life may be used to indicate the general operating condition of the lamps and carbons and to compare lamps and carbons of the same or different makes. The life is dependent on the enclosure to a greater extent than on any other influence.

TABLE I.—EFFECT OF ENCLOSURE ON LIFE.

No.	Diam of carbons in.	Diam of gas cap opening in.	Clearance area in per cent. of carbon area per cent.	No. trims tested	Ave. arc volts	Ave. amperes	Ave. hours	Life per cent.	Condition[2] of points
1	0.874	0.900	6.16	5	63.5	7.7	116.7	100	Good
2	0.874	0.930	13.5	3	62.9	7.4	115.6	99	Good
3	0.874	0.960	21.2	4	61.7	7.4	98.4	84	Fair
[1]4	0.874	1.000	31.6	5	65.7	7.7	92.0	78.8	Poor
5	0.874	0.900	—	1	65.0	7.5	41.0	.	Very poor

The life is determined to some extent by the arc wattage, higher wattage tending to give shorter life. Spindling of the carbons produced by high current, irregularly shaped points and the change of atmosphere accompanying arc rupturing all tend to shorten the trim life.

The burning ratio between the two carbons in focusing type lamps must be retained as designed by the lamp maker in order to secure an advantageous use of the carbon. Any change in the regularity of carbon consumption that will alter this ratio will change the light steadiness and distribution, vary the globe deposit and may result in the destruction of lamp parts by the heat of the arc. Globes that leak and, in direct current lamps, reversed polarity are the most common causes of change of burning ratio.

Color.—Quantitative methods satisfactory for measuring color as a characteristic of the light of flame arcs have not been provided. Various methods are being used in laboratories but they are not sufficiently perfected to permit their general use. A standard for the color of flame arcs has not yet been established and in most instances the name given to the color of the light depends upon the superficial impressions of the casual observer. This is especially so when comparisons are attempted.

[1] An inner globe with a hole 3 inches in diameter was used in this case. No outer globe

[2] This refers to the amount of slag on the carbon points at the end of the test; points free from slag are called good.

When color standards are being fixed, thought should be given to the possibility of meeting them with available flaming materials. The known yellow flame materials are cheaper and more efficient than any others at present available, while the white flame materials are more expensive and less efficient. This has much to do with the fact that the least expensive and most efficient flame carbons now on the market give a yellow light.

When color comparisons are attempted the observer should endeavor to have the lamps used in as nearly identical conditions as possible. The current, enclosure and surroundings should be the same. It is not practical to use over four lamps at the same time and the eyes should not be concentrated on the arcs for more than a few seconds. If possible, an image of the light should be watched rather than the arcs themselves. All glassware should be clean and should be used first in one lamp and then in the others in order to eliminate from the final result the effect of absorption. Different colored back grounds will influence the apparent color. This should be carefully noted when street tests are conducted at night. All trims should be burned an equal length of time in the lamps.

Any results obtained by such tests as just mentioned are but crudely comparative and will not show small color differences. A simple illustration of the inability of any comparative tests to give a true color measure, when conducted as just mentioned, is as follows: a cream white light compared with a snow white light appears yellow; when compared with a yellow light it appears much whiter than in the first case.

Efficiency.—"The efficiency of electric lamps is properly stated in terms of lumens per watt at the lamp terminals" (American Institute of Electrical Engineers standardization rules). In any statement of efficiency the color of the light and the method of determination must be given to make the record complete.

All candle-power measurements of total flux of light should be made in an integrating sphere. This gives a direct reading of the mean spherical candles and is the most accurate method of securing this information, considering the time and labor involved.

TABLE NO. 2. EFFECT OF CURRENT AND ARC VOLTAGE ON CANDLE-POWER.

Rated arc volts	No. of tests	Arc volts	Amps.	Mean spherical candle-power	Per cent. average deviation	No. of tests	Arc volts	Amps.	Mean spherical candle-power	Per cent. average deviation
		6.0 Amperes					7.5 Amperes			
45	3	46.3	5.6	379	13.3	3	45	7.5	579	11.8
55	3	55.3	6.0	479	14.2	5	55.2	7.2	641	12.3
65	3	63.7	6.0	624	12.3	5	64.2	7.5	769	16.2
70						6	70.7	7.5	891	15.4
		10.0 * Amperes					15.0 Amperes			
45	2	44.9	10.1	773	19.3	3	45.0	14.9	1376	13.7
55	3	55.2	10.2	1043	14.6	3	56.7	15.4	1612	15.7
65	4	65.3	10.3	1082	15.3	3	64.3	15.3	1891	15.1

Lamp: Alternating current multiple 110 volts, 60 cycles

Current adjustment made by shunting solenoids.

Voltage adjustment made on choke coil.

Carbons: Standard yellow flame carbons, designed for service at 7.5 to 10 amperes and 65 volts at arc.

* $\frac{\text{Apparent arc watts}}{\text{True arc watts}} = 0.94$, —— 0.90, —— 0.94 for the respective lots at this current.

Measures of candle-power in given directions or upon selected planes may be obtained by special devices and when properly handled give comparable data. The light in any direction or on any plane depends upon the lamp design and position, consequently such values do not give a true measure of the arc efficiency. Measurements of candle-power given by an electric arc lamp are attended with the difficulty of measuring a continually fluctuating source. This requires that only average values may be trusted and these should be accompanied by an average deviation measure. The number of readings to be taken should be such as to reduce the influence of inaccuracies of the photometric device itself to a value that is less than the influence of the fluctuating source itself. The following table will show the influence of some factors upon the mean spherical candle-power. Any variation in the total flux of light from the arc will affect the candle-power in any given direction or upon any plane ordinarily measured. The writers do not possess any data that would permit them to say to what extent a variation in total light flux would influence the directional candle-power.

TESTING OF CARBONS FOR ENCLOSED FLAME ARC LAMPS.

The tests outlined under the various headings are such as most lamp owners can readily make. The object of the tests is to obtain a measure of the extent to which the respective characteristics just considered exist in the carbons and to determine their value for the service desired. All final results should be averages. Most of the tests are matters of record and need no explanation.

Accuracy of Tests and Number to be Made.—The accuracy of the information must be balanced against the cost of obtaining it, in determining the number of trims to be tested. The accuracy of any individual when conducting a test in any lamp cannot be forecasted. Tests should be conducted with all care consistent with their value to the observer and he should be particularly careful to duplicate conditions from trim to trim. The slagging tendency and life of carbons should be determined from the results of tests of at least 100 trims and the values expressed in percentage. Sufficient information about the candle-power, color

and steadiness may be secured from a smaller number of trims. At least five trims should be tested and these checked with a second set of an equal number of trims if data of greater accuracy are desired.

Apparatus Required.—It is assumed that these tesst are to be made by a person who has lamps at his disposal. Ammeters, voltmeters and if possible wattmeters should be secured. For photometric work, a sphere and photometer of the Sharp-Millar type is most desirable. Directional measurement devices may be used along with the familiar photometer benches and boxes. There are various types of illuminometers on the market that may be used.

Cost of Testing.—Most of the tests will cost but little more than the cost of the current used, and the increase over the current cost will be for time spent in trimming and observing. The measurement of candle-power is the most expensive test since it includes the cost of the instruments required, at least two people to make observations and the cost of the current.

OUTLINE OF TESTS.

Reliability in Operation.

Object.

To determine whether slag is formed and, if so, the amount in a definite time when the lamp is operating normally.

Records to be Made.

1. Number of tests made.
2. Type of lamp and kind of current.
3. Number of outages from slag.
    - *a.* Time in life of trim.
    - *b.* Cause.
        1. Carbons.
        2. Lamp conditions.
    - *c.* Location, kind and amount of slag.
4. Record of current and voltage (line and arc).

Steadiness in Operation.

Object.

To determine the presence, extent, cause and possibility of eliminating rupturing, flickering and fading.

Records to be Made.

a. Rupturing.

1. Number of tests made.
2. Type of lamp and kind of current.
3. Number of arc breaks per unit time.[1]
4. Period of trim life when observed.
5. Arc voltage and current.
6. Shape of carbon points.
7. Condition of lamps—whether normal.

b. Flickering.

No adequate measure of flicker has been obtained. Attempts to count the flickers per minute show practically the same results in a badly flickering light and a steady light. Photometry is of little help on account of rapidity of the changes. The following is as good a test as any.

1. Number of tests made.
2. Type of lamp and kind of current.
3. Percentage of time the light flickers.
4. Nature of change, whether in color or intensity or both.
5. Comparison with a standard carbon in adjacent lamp.
6. Examination of the arc through colored glasses, noting condition of arc producing flicker.

c. Fading.

The extent to which a light fades can best be determined by running simultaneous tests in adjacent lamps noting:

1. Number of tests made.
2. Type of lamp and kind of current.
3. The average deviation in candle-power.
4. Percentage of time of faded light.[2]
5. Period in trim life fading occurred.

[1] An automatic counter can be placed in most lamps that will give the data needed here by reading it from time to time.

[2] By fading in this record is meant the time the light does not have the normal color or the candle-power is below the mean.

Life.

Object.

To determine the average burning life of a trim of carbons in any type or make of lamp. The results may be used to determine the condition of operation of the lamp and carbons, and their suitability for the service desired.

Records to be Made.

1. Number of tests made.
2. Type of lamp and kind of current.
3. Total burning hours.
4. Burning hours per inch of each carbon consumed.
5. Current, line and arc voltage.
6. Condition of lamps.

   NOTE.—Record No. 4—Hours per inch of each carbon—is made to show the burning ratio of the carbons with respect to one another.

Color.

The problem of devising adequate measures of color, particularly for fluctuating light sources of the characteristic of the flame arc, has not been satisfactorily solved. The chief difficulty in devising tests is to eliminate the personal element. Beyond recommending that all conditions surrounding comparative tests be as nearly identical as possible, the authors cannot specify other tests for color measurement.

Efficiency.

Object.

To determine the mean spherical candles per watt, either terminal or arc, or the candle-power in some desired direction.

Records to be Made.

1. Type of lamp and kind of current.
2. Number of readings taken.
3. Average of readings whether mean spherical, directional or foot-candles.
4. Average watts.
   a. Terminal.
   b. Arc.

5. Candles per watt.
    a. Terminal watts.
    b. Arc watts.
6. Line and arc voltage and current.
7. Length of time lamp burned before readings were taken.
8. Duration of reading period.
9. Average deviation of readings.[1]

Let M = mean value.
N' = number of readings greater than M.
$\Sigma N'$ = summation of readings greater than M.
N = total number of readings.

$$\frac{2(\Sigma N' - N' \times M)}{N \times M} \times 100 = \text{per cent. average deviation.}$$

DISCUSSION.

MR. S. L. E. ROSE: In this paper there are a few things upon which I would like more information. At the bottom of the second page this statement is made: "A consideration of the factors causing slag to form will make testing more valuable, since the tests will serve their greatest value when they record the occurrence of the slag and afford some clue as to the cause of formation." I might say in this connection that in some tests at the laboratory with which I am connected, we have found that if, after trimming a lamp and before burning it for a considerable length of time, it is turned off and on a number of times it will have a much greater tendency to slag. After four or five hours burning, however, it can be turned on and off without this danger of slag forming. I do not know why this should be the case, but it is so, and it would seem to be borne out by the fact that in regular street service this trouble is not experienced. Perhaps the authors have encountered this difficulty and can tell me the cause.

In regard to the burning life of carbons it would be interesting to know whether it is the same for the same arc wattage.

As regards white and the yellow carbons, there are some makes that have nearly the same efficiency. I have in mind a foreign carbon in which there is practically no difference in efficiency

[1] The following formula may be used to calculate the average deviation and may be applied to candle-power or any other series of results of observations.

between the white and yellow carbons. It is only fair to state however, that the color difference is not so marked as it might be.

At the bottom of the eighth page of his paper under the heading *Efficiency*, Mr. Baldwin quotes from the standardization rules of the American Institute of Electrical Engineers, as follows: "The efficiency of electric lamps is properly stated in terms of lumens per watt at the lamp terminals." In table 2 he has given a lot of spherical candle-power figures without giving the watts. I think these figures should be given so that the lumens per watt could be obtained.

Mr. R. B. Hussey: I think Mr. Baldwin has given us a very excellent paper covering experimental work on flaming carbons, but it seems to me that perhaps it will leave a wrong impression, as a whole. In reading this paper, a natural inference would be that there are no satisfactory flame carbon arc lamps at the present time. This is, however, not the case as there are more than five thousand lamps of the enclosed flaming arc variety of as many as three different makes in satisfactory operation in this country to-day. I have been told that these are operating under regular street lighting conditions, with an outage of not over one-half of one per cent., which is certainly very good for ordinary street service.

Mr. C. E. Stephens: I am sure that all of us appreciate this excellent paper, particularly in connection with the development of the flaming carbon arc, which is the highest efficient large candle-power unit on the market.

I would like to ask a few questions regarding this paper. In table 1, Mr. Baldwin gives the diameter of the carbons in inches and the diameter of the gas cap openings in inches, with the effect of the enclosing of the carbons on their life. I would like to ask what variation in the diameter of the carbons might be expected in ordinary commercial production? Suppose, for example, we desire to produce a carbon having a diameter of 0.874 inch, approximately what would be the variation, above or below this figure, in the diameter of such a carbon in commercial production?

I note that table 2 showing the effect of current and arc voltage on the candle-power has been prepared from data on the

use of yellow flame carbons. I would like to ask what effect, if any, would be noticed on the candle-power of the arc in varying the current and voltage of white carbons instead of the yellow carbons?

Mr. H. T. Spaulding: The authors rate steadiness in operation as second only to reliability in importance among the desirable qualities of a flame arc. The paper states that photometry is of little help in determining the element of flicker. While

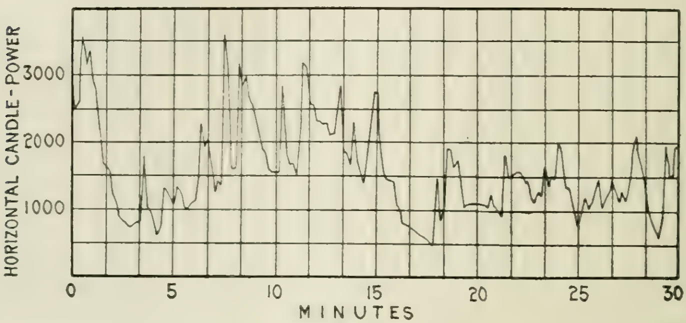


Fig. A.

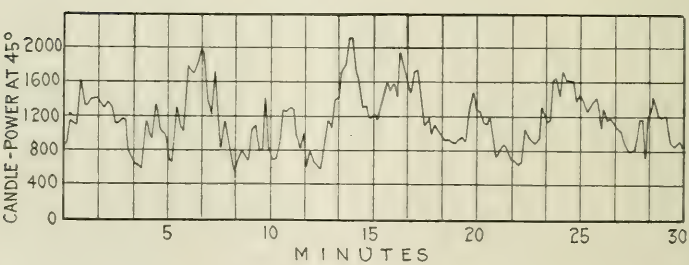


Fig. B.

photometric observations by no means tell the whole story and may be of doubtful value for comparing different electrodes, they are of some assistance in indicating the order of variation in candle-power due to fading and to flicker. This is illustrated by the tests on flame lamps of two different types as shown in figs. A and B. In each case candle-power readings were taken every ten seconds for a half hour with the aid of a single-mirror selector. The lamps were carefully trimmed, supplied with new

electrodes and operated for one hour previous to the tests. The voltage of the circuits varied less than one-fifth of one per cent.

Fig. A represents the performance of a direct current multiple enclosed flame lamp. It will be noted that the candle-power varies from 500 to 3,600 and that, while the average value is in excess of 1,500, the mean intensity for some five-minute periods is very much lower.

Fig. B gives the results secured with an alternating current multiple enclosed flame lamp of a later type. It is apparent that the average intensity of a flame arc lamp should be used only with due allowance for this extreme variation.

Mr. A. T. Baldwin (in reply): The average deviation in life that was obtained for table 1 is as follows:

No.	Diam. gas cap opening in inches	Average deviation in hours
1	0.900	4.6
2	0.930	3.0
3	0.960	9.1
4	1.000	7.4

A tendency toward a greater variation in life from a carbon of predetermined diameter is manifest with larger gas cap openings.

The relation between variation in carbon diameter and life with constant gas cap opening is complicated by a number of other factors. The gauging limits to which it is practical to work, and the allowable diametral clearance area in per cent. of carbon area depend considerably upon the size of the carbon, so that no statement applicable to all conditions can be made.

The phenomenon of an initial slag period has been observed in the laboratory with which I am connected. With normal operation the burning end of the electrode consists of a very thin layer of carbon particles overlying the normal electrode material. Directly upon starting with unburned carbons, the flame material is mixed with this carbon layer. This condition and the rapid consumption of carbon when starting with a globe full of fresh air, tends to form the initial slag. It may take from a few minutes to a half hour for the arc to adjust these conditions during which time no attempt should be made to regulate the lamp.

The mean spherical candle-power results that one would get

with white flame carbons with varying current and voltage would closely resemble those given by the yellow flame carbons as recorded in table 2 within the operating current and voltage range of the particular white flame carbon tested. This is a subject that is too broad for a short discussion. Many so-called white flame carbons really give a strong yellow-white light and will give values closely approaching those for the yellow flame carbon in table 2.

PRESENT PRACTISE IN SMALL STORE LIGHTING WITH TUNGSTEN FILAMENT LAMPS.*

BY CLARENCE L. LAW AND A. L. POWELL.

The purpose of this paper is not to present any new ideas on a particular phase of lighting, but rather to give the results of a recent investigation of the lighting of small stores carried on under our direction. The object in collecting the data here given was as follows. We know that there are thousands upon thousands of small stores throughout the country, any of which is typical of its class. In the main, these are not of sufficient importance to be treated separately or individually by the illuminating engineer. Therefore, if a set of approximate rules could be put in the hands of the central station or manufacturer's solicitor, with the aid of which he could intelligently design such lighting installations, a distinct step should be made in the advancement of the art of illumination.

Since, as we have suggested, it seems somewhat desirable to standardize the practise in small store lighting, and knowing that this can best be done by the method of averages, we proceeded to determine the present state of the art and to interpret the observed values. Another point which must be recognized, is the fact that any individual case compared with the average is liable to be deficient and one must apply his experience to values like those recorded in this paper if he would attain the best practise.

With this end in view, over eight hundred small stores were visited in New York City, Newark, and the adjoining towns. In order that the installations investigated should represent average conditions throughout the country, only stores on the less prominent avenues and cross streets were visited. Fifth Avenue, Broadway, 14th, 23rd, 42nd, 125th Streets, New York, Broad and Market Streets, Newark, and like streets were carefully avoided as not typical of the small stores through the country.

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

The shops along Fifth Avenue, and the like, although small in dimensions, cater to such an exclusive class that individuality of treatment is essential in their illumination. The stores along some of the other avenues mentioned are apt to produce a blaze of light for the advertising value rather than to illuminate their stores and hence are not typical of our classification. Corner stores were not included as it was apparent that their standards were invariably higher than the stores located along the block, due to the tendency toward display lighting.

At each store, the following facts were noted and carefully tabulated: address; type, and nationality of the proprietor; dimensions of the store; number of lamps; class, clear or bowl-frosted; reflector equipment; arrangement of lamps; watts per square foot; color of ceiling; color of walls; height of ceiling; height of lamps. Show window: number of lamps; arrangement; wattage; class, etc.; reflector and general remarks.

All these data were taken in order to afford a means of ferreting out errors and discrepancies.

For the purpose of simplifying the issue of our investigations, the results were obtained in watts per square foot, on account of the similarity of the units and because this value serves roughly as an indication of the cost and, with close approximation, the quantity of light. These values could not be applied to arc lamps or other electric illuminants; they are based on the use of tungsten filament lamps and efficient reflectors.

One fact which was apparent in almost all these stores is that the show window lighting helps the lighting in the fore part of the store interior. There is usually no dividing partition between the store and the window. Hence the values given for watts per square foot, which take in account only the units in the store proper, would be low if the window were separated from the store by an opaque wall.

The wattage required for any desired intensity in store lighting will naturally be higher if the illumination is necesasry on the side walls rather than on a horizontal plane. The recommended values in the table given further on are based on the assumption that a reflector of relatively high efficiency will be used, and, of course, should be modified if some purely decora-

tive shade is adopted, or if indirect or semi-indirect lighting systems are installed.

Photographs were taken in the stores lighted at night of typical installations of each of the main classes and are given to supplement the text.

The brief discussion given below applies to store lighting in general and although this topic has been discussed before, we believe it will bear repetition.

Fig. 1.—Lighting typical of art stores in the small-store class.

Store lighting is of primary importance, for the successful storekeeper must be up-to-date and progressive in all phases of his business. In this age of competition, particularly in the retail lines, to be ultimately successful the shopkeeper must carefully scrutinize every detail of his store layout, and business methods. That is, his store must be arranged to attract the public; then, when he has their trade, he must keep it. There must be nothing which will tend to displease customers and cause them to go elsewhere. Just as his clerks must be courteous in order to retain

the patronage of the public, so must his lighting be arranged with the same object. Not only must there be the correct quality and quantity of light to insure an advantageous presentation of goods, but there must be no discomfort arising from the lighting system, such as eye fatigue, which may cause the customer to go where he or she can shop in comfort. The system must also be such that the cost to produce the desired effect is at a minimum, thus keeping down that eternal bugbear, overhead charges.

Fig. 2.—Lighting typical of bakeries in the small-store class.

Three primary factors entering into the consideration of store lighting are: (1) intensity, (2) color, (3) even distribution of light.

The small store proprietor is usually limited as to the amount of money he can spend for lighting, and hence the psychological and artistic sides of the layout are, in a measure, out of the question. The light sources should be efficient and the system permit of an economic maintenance.

INTENSITY.

It is a well-known fact that there is a certain range of desirable intensity of illumination for each class of work in a factory; similarly, there are certain desirable ranges for different goods on display at the various stores. It is often remarked that modern illumination brings out bad qualities in the goods. This is sometimes true, but these defects are at once recognized as inherent in the materials themselves, rather than as a fault of

Fig. 3.—Lighting typical of barber shops in the small-store class.

the lighting. Here the engineer is in a quandary. Shall he show up these faults to the prospective purchaser, or shall he render them unnoticeable? The latter condition is sometimes imperative, as he is working primarily in the interest of the owner of the store. For instance, we encountered a second-hand furniture dealer in the poorer section of New York. This merchant was rabid in his fancied objection to the tungsten lamp—it showed too readily the imperfections in his goods. The only difficulty was that he had too high an intensity of illumination,

and on using a smaller size unit obtained satisfaction. Of course, in the average store the intensity should be such that it brings out the good qualities perfectly. It is obvious, for example, that a black gas range will require a different intensity of light than a piece of white dress goods.

COLOR OF LIGHT.

While in the large department stores the color of the light is of some importance, in the class of stores mentioned in this

Fig. 4.—Lighting typical of cigar stores in the small-store class.

paper there is so little matching of goods, that we may safely avoid a discussion of it. In point of fact, many of the large store proprietors have adopted tungsten filament lamps throughout, which, though they do not give an absolutely pure white light, afford a close approximation to it and are suitable for most purposes. Moreover, the cheerful appearance of the whole building when lighted with these lamps is an attractive feature.

EVEN DISTRIBUTION OF LIGHT.

Light distribution is one of the essential factors to be considered in designing a lighting installation for a store. Deep shadows should be avoided, and all places where the goods are on display should have an equal share of the total flux of light. We can readily accomplish this by the proper spacing, height and

Fig. 5.—Lighting typical of clothing stores in the small-store class.

choice of reflectors. The method of determining these conditions is too well understood to warrant giving the details here.

CLASSES OF SMALL STORES.

Art Stores (Fig. 1).—In a store like that shown in fig. 1 the walls on which the pictures are hung form the planes of illumination. Preferably these should be specially lighted to the desired intensity with a low value of general illumination for the center of the store. This, however, involves considerable additional expense of installation and maintenance and rarely finds application in the small store.

If the store is of medium width two rows of relatively small units (40-60 watt), located as shown in the picture, equipped with bowl shaped opalescent or prismatic reflectors giving an intensive distribution are applicable. Both the diffused and the direct light give even illumination over the picture surfaces and there is sufficient general illumination.

If the store is very narrow and one row of units is adequate,

Fig. 6.—Lighting typical of confectionery stores in the small-store class.

the lamps should be equipped with a distributing type reflector and hung high.

Comfort is desirable in viewing the exhibition; glare should be especially avoided; bowl-frosted lamps are necessary.

The average watts per square foot found was 1.0. We believe this value to be a trifle low to give good results; 1.3 watts per square foot is recommended.

Bakeries (Fig. 2).—The counters and pie racks require the illumination. Although not in the particular instance shown (fig. 2) a mirror is usually found in the rear of the counter the

reflection from which assists the lighting. A single row of light units located in the center of the store serves very well. These may be small and located on multi-arm fixtures, or larger on single stems. Reflectors should be bowl shaped and give an extensive distribution. The average watts per square foot found was 0.82. As the ceilings and walls are usually light and clean this is a good working value.

Barber Shops (Fig. 3).—The faces of the patrons furnish the

Fig. 7.—Lighting typical of delicatessen stores in the small-store class.

plane of illumination; and as the patrons are forced to lie back and gaze upon the ceiling light diffused as much as possible is desirable. The row of chairs is usually located about two feet from under a center row of lights and there is considerable glare if a clear lamp with a prismatic reflector is used. A mirror is almost invariably located in front of the chairs and this tends to neutralize the effect of the deep colored wall papers which are used to a great extent in the cheaper shops. One 60-watt bowl

frosted tungsten lamp equipped with an opalescent or frosted prismatic reflector giving an intensive distribution, hung about 7 feet, 6 inches (2.28 m.) from the floor, placed between each two chairs even with the top of the back will give an excellent light for hair cutting; and, for shaving, the maximum light will be on the under part of the patron's chin. There will be sufficient diffuse light for general illumination. The average watts per square foot found (general illumination) was 1.23. This is

Fig. 8.—Lighting typical of drug stores in the small-store class.

about correct for an installation like that shown in fig. 3, but the localized arrangement is to be preferred.

Cigar Stores (Fig. 4).—Show cases or shelves occupy at least one wall. The paper or wall is usually dark, tending to increase the wattage necessary to properly illuminate the store. While the discernment of detail is not so very necessary, the dark color of the goods and their low reflecting power also add to the light required. The planes of illumination are the counters and show cases. Medium sized tungsten lamps with intensive opalescent

or prismatic, bowl or flared, reflectors located over the counter serve well. The average watts per square foot was 1.45. This is a good working value, as these stores are very small in size and a pleasing appearance is essential.

Clothing Stores (Fig. 5).—The walls of this type of store are usually lined with hanging suits or show cases; these as well as the center portion of the store must be lighted to permit inspection of the goods. Although the clear prismatic reflector is

Fig. 9.—Lighting typical of dry goods stores in the small-store class.

usually found in conjunction with the tungsten lamp the frosted prismatic or opalescent reflector is to be preferred on account of the greater diffusion or "softness" of the light. A row of large units singly, or smaller units grouped on fixtures, is suitable, with a local light for the mirror. The goods are to a large extent very dark and require more than the usual amount of light. We recommend raising the value of the average watts per square foot found, 1.37, to 1.5.

Confectionery Stores (Fig. 6).—These stores are usually as

showy as possible and decorative fixtures predominate. Mirrors and shelves occupy nearly all the wall space. Quite frequently decorative wall brackets are placed alongside of the mirrors. The shades (it is hardly possible to call them reflectors) used in the average confectionery store are purely decorative. Clear lamps and a blaze of light seem to be desired. In lighting these places the ideas of the owner should be given due consideration; if a decorative system is demanded the most efficient

Fig. 10.—Lighting typical of florists stores in the small-store class.

system that accomplishes this end should be used. Multi-arm fixtures with a number of small units are popular and are usually equally spaced in a row between the two counters. Good results should be obtained using about one watt per square foot; the average found was 0.97.

Delicatessen Stores (Fig. 7).—The stores of this class are usually very narrow and are best lighted by a single row of light units located over the counter. An extensive type of reflector should be used as the shelves and show cases which occupy both

side walls are the principal planes of illumination with the counter as a secondary consideration. The average watts per square foot found was 1.1. This value will give a cheerful and well lighted store.

Drug Stores (Fig. 8).—Here the walls are lined with shelves holding bottles and packages. The labels must be read easily. The tables and counters must also have a fair amount of illumination. The stores are of medium width and are best lighted

Fig. 11.—Lighting typical of haberdashery stores in the small-store class.

by two rows of units using reflectors giving an intensive distribution. Sufficient diffused light will thus be provided for the shelves in addition to well distributed downward flux. The average watts per square foot found was 1.0. We believe this value a trifle low and would recommend using 1.2 watts per square foot in calculations.

Dry Goods (Fig. 9).—Very frequently in the small store of this kind goods hang from the center of the ceiling, and shelves line all sides of the store. A general illumination of a relative-

ly high intensity for the little color matching which is done, is necessary. The counter forms the plane of illumination, as all inspection of goods is done there. A good lighting arrangement for two counters is a row of small lamps with intensive reflectors over each, furnishing localized general illumination. If, as shown in fig. 9, the center of the room is occupied by a table, general illumination from a multi-arm fixture is applicable. The average watts per square foot was 1.26. On account

Fig. 12.—Lighting typical of grocery stores in the small-store class.

of the large percentage of white material on the shelves and hanging about the store, good results could be obtained with 1.0 watt per square foot.

Florists' Stores (Fig. 10).—A good arrangement is general illumination localized on the show cases. This is the more economical arrangement, as the intensity in the main portion of the store need not be high. Lamps with prismatic or opalescent reflectors of an artistic type serve well. The average watts per square foot found was 1.0. If only general illumination is used,

this figure is suitable. If show case lighting is installed 0.5 watt per square foot is sufficient for general illumination.

Haberdashery Stores (Fig. 11).—As is the case in a number of other instances, a higher intensity of illumination is found in the front portion of the store, as most of the purchasing is done there and this arrangement also has some advertising value. Bowl reflectors of the intensive type spaced to give an even illumination on the counter plane serve very well. The average

Fig. 13.—Lighting typical of jewelry stores in the small-store class.

watts per square foot found was 1.43; this average is a good working value.

Grocery Stores (Fig. 12).—The shelves and counters here demand an equal amount of the light; and if the store is very narrow one row of single units using a wide angle or flared reflector is suitable. For a medium width store as shown two rows of single smaller units with intensive opalescent or prismatic bowl reflectors should be used. The average watts per square foot was 0.98.

Jewelry Stores (Fig. 13).—Direct light of high intensity should illuminate the counter. Lamps with intensive prismatic reflectors, located in a row over the counter will accomplish the desired result, and there will be sufficient diffused illumination to light the show cases usually found in the rear of the counter. Clear lamps with opalescent or other diffusing reflectors will give a brilliant light and permit the jewels to sparkle. Another arrangement is the one shown in fig. 13, namely the use

Fig. 14.—Lighting typical of meat markets in the small-store class.

of crystal glass fixtures hung high, furnishing a brilliant general illumination. 1.54 average watts per square foot is good practise.

Meat Markets (Fig. 14).—The walls on which the meat racks are located are the surfaces to be lighted, hence with a single row of lamps equipped with distributing reflectors, hung about 9 feet (2.74 m.) is necessary, or with two rows of lamps with bowl shaped intensive reflectors; these arrangements will provide sufficient direct light for the counter. A local light must

be provided for the ice box, and it is well to have a small lamp wired in series with this lamp, on the outside of the box to serve as a signal lamp. The cashier's desk should also have a small local light. 0.9 average watt per square foot is satisfactory.

Millinery Stores (Fig. 15).—The hats are displayed in high glass cases lining the walls, but all close inspection is done in the center of the room. Two rows of lamps with intensive reflectors will serve very well in lighting the show cases, and at the

Fig. 15.—Lighting typical of millinery stores in the small-store class.

same time provide good light for inspection. In the narrow store a single row of lamps with intensive reflectors is applicable. 1.3 watts per square foot is a very good working average.

Music Stores (Fig. 16).—Shelves with boxes line the walls. The contents of the boxes are indicated by writing or printing on the face of the box. The light for this kind of store must be of a moderately high intensity and the reflector equipment for the arrangement chosen should give a wide distribution of light.

1.05 average watts per square foot will serve as a basis for making calculations.

Restaurants (Fig. 17).—The tables are the places on which illumination is desired. The intensity of the illumination should be sufficient to permit one to read easily. Although the ceiling is usually white, the walls are frequently covered with a rather dark paper; occasionally they are, however, interspersed with mirrors. The dark walls require a wattage slightly higher than

Fig. 16.—Lighting typical of music stores in the small-store class.

normal for a given illumination. The room should be laid out in the regular manner for an even distribution on the working plane. As a rule restaurants are wider than most small stores; two rows of lamps are usually necessary. The average watts per square foot required is 1.1.

Shoe Stores (Fig. 18).—The plane of illumination here is about one foot above the floor, and there are secondary planes which are the surfaces of the boxes lining the walls. Sufficient light must strike these to enable the clerk to read the labels. Two

rows of lamps with intensive reflectors serves very well. The customers' bench is usually located in the center of the room between the rows. Clear lamps are best as a direct light seems to make the leather appear to better advantage. A machine is usually found in the rear. It requires a local light with a proper steel reflector. The average watts per square foot required is 1.0.

Stationery Stores (Fig. 19).—Much the same conditions exist

Fig. 17.—Lighting typical of restaurants in the small-store class.

here as in the cigar stores; that is, the walls are dark, and one side is lined with shelves. The counter is usually covered with a show case. A row of lamps with intensive reflectors over this will light the room well.

The average watts per square foot found was 1.02. This is about right.

Wine and Liquor Stores.—Barrels occupy the rear portion of the store; shelves, with bottles, are on the sides. The fixtures

are usually decorative, and there is no definite plane of illumination, as the shelves and counter demand equal amounts. A distributing or extensive reflector is applicable. 1.2 average watts

Fig. 18.—Lighting typical of shoe stores in the small-store class.

per square foot, the average found, is slightly high; 1.0 is a better working value.

GENERAL CONCLUSIONS.

From the few examples given above one may make the following classification and specifications for small stores:

1. Those stores which demand equal illumination on the side wall shelves and on the counters, such as bakeries, china, delicatessen, drug and grocery stores and meat markets. If a store is of medium width,[1] two rows of lamps with intensive reflectors, or one row of multi-light fixtures with wide arms will be satisfactory; if narrow, one row of lamps with extensive reflectors.

[1] The medium width stores we have in mind average about 20 feet; their lengths vary; 50 feet may be considered the maximum length.

Some of the smaller stores occupy only half a city lot and are approximately 9 feet wide and stores of this width come under the narrow classification.

2. Those which demand good illumination on the counters with a smaller amount of light flux on the side walls, such as cigar, dry goods, fish, haberdashery, jewelry, pawn broker and stationery stores, rows of relatively small lamps with intensive reflectors providing localized illumination with reference to the counters, serve well.

3. Those stores which demand the highest intensity on the wall surfaces and a low general illumination. Art, music, hard-

Fig. 19.—Lighting typical of stationery stores in the small-store class.

ware and paint stores fall in this class. Two rows of relatively small lamps with intensive reflectors located close to the wall, or if very narrow, one row of lamps with distributing reflectors.

4. Those which demand diffuse general illumination. In this class are clothing, confectionery, florist, furniture, novelty, millinery, tailor, shoe, trunks and leather, wine and liquor stores, and restaurants. Decorative fixtures and equipment, or simple units arranged for even illumination on the theoretical working plane may be provided.

5. Those stores the illumination of which is a localized lighting proposition, as in barber shops, hair-dressing and manicuring parlors.

Fig. 20.—Lighting typical of wine and liquor stores in the small-store class.

The following table gives a summary of the values found:

Type of store	No. investigated	Watts per square foot Max.	Min.	Aver.	Recommended
Art stores	14	2.02	0.40	1.01	1.3
Bakeries	29	1.74	0.25	0.82	0.8
Barber	34	2.62	0.51	1.23	—
Cigar	29	2.00	0.39	1.45	1.4
Clothing	78	3.12	0.27	1.37	1.5
Confectionery	30	2.38	0.26	0.97	1.0
Delicatessen	29	3.36	0.37	1.11	1.1
Drug	24	1.85	0.43	1.01	1.2
Dry Goods	28	2.50	0.69	1.26	1.0
Florist	13	1.59	0.48	1.07	1.1
Grocery	53	2.73	0.30	0.98	1.0
Haberdashery	23	4.95	0.60	1.43	1.7
Jewelry	26	4.38	0.50	1.54	1.6
Meat Markets	32	2.42	0.40	0.91	0.9
Millinery	27	4.16	0.30	1.28	1.3
Music	11	1.85	0.60	1.05	1.1
Restaurant	27	3.20	0.42	1.08	1.1
Shoe	31	1.87	0.36	0.98	1.0
Stationery	35	2.40	0.45	1.02	1.0
Wines and Liquors	25	2.89	0.40	1.20	1.0

The authors desire to take this opportunity of thanking Messrs. S. W. Van Renselaer and L. E. Voyer for their assistance in collecting the data given in this paper, also the photographic department of the New York Edison Company, through whose courtesy the photographs are printed.

DISCUSSION.

MR. JOSEPH E. PUTNAM: The thing that has impressed me in this paper is the apparent falsity of the pictures as regards the illumination. I have charge of the street lighting in Rochester, and we have tried over and over again to make a picture at night which would show some approximation of the truth. There are several difficulties about the reproduction of illumination in photographs. In the first place, the presence of bromide of silver in the plates makes them particularly sensitive to the blue and very little to the red in the spectrum. Another difficulty, and one which is shown very markedly in the illustrations in this paper, was halation. One gets a glare of apparent light about the source and that does not tell the truth. I think in none of the pictures shown could one even guess at the form of fixture used with the lamps. Some of the experiments which I have made have shown that some improvement is possible by the use of panchromatic plates and a two-solution developer—to start the development of the plate—with a very small amount of alkali, and I want to offer this suggestion to those who have trouble along this line. The exposure should be sufficient to give full value to the shadows. Many of the stores shown in this paper were probably very brightly lighted, but they do not show it.

DR. H. E. IVES: Perhaps some of the work of the "high-brows" can be made of practical help to the practical man right here. Some years ago a problem arose in regard to photographing eclipses of the sun, when great extremes of brightness must be recorded upon the plate. This was solved, I think quite satisfactorily, by the manufacturers of photographic plates, by the making of a special plate with a triple coating. If there is going to be a great deal of photographing of lighting installations by the big companies, I think it would be well for the plate manufacturers to bring out a plate along these lines.

MR. H. C. STERLING: This paper touches closer the class of illuminating engineering I am up against every day, than any thus far presented before the convention; and I wish to assure the authors, that I, for one, fully appreciate it. My experience as a manager of a central station in a small community has been that what the small-store merchant seems to want is glare. Some years ago, you will remember, the Nernst lamp was introduced. This lamp was efficient and with the glassware used at that time produced a fairly strong soft diffused light. It began to cut in on the lighting business of the gas man. Then came the mantle gas "arc" in clear glass globes, a perfect glare of light. Not to be out done, the electric light man brought out the white tungsten lamp in all sizes and shapes with its glare. The great trouble seems to be that the consumer (and, I regret to say, too often even the owners and managers of plants themselves) don't know the difference between light and illumination.

MR. J. R. CRAVATH: As a manager of central stations in small communities, I have found, as the previous speaker stated, that the small store merchant wants glare from his lighting installation. It is surprising though to see how quickly any community will respond to any effort to provide better lighting. I think it is a good deal a question of the kind of example which the central station sets itself and also the amount of effort which it puts forth among its customers. Of course there is a certain class of customers who cannot be convinced but that the more glare they have, the better their lighting is.

MR. H. THURSTON OWENS: The conditions and recommendations cited in this paper cover only direct lighting. We are destined to see important improvements in the form of semi-indirect lighting in small as well as large stores.

MR. A. J. MARSHALL: Several glassware and fixture manufacturers now have committees investigating conditions and erecting ideals for various classes of lighting. Central stations and gas companies also realize that it is a very much better proposition to establish individuality of design, not necessarily for embellishment, but for attractiveness. It is decidedly improper to put the same kind of an installation into a millinery shop that you would use in a delicatessen store. In one case the illumina-

tion required may be only one foot-candle; in others it may be five or even ten foot-candles.

There is a very practical side to this question, and that is the question of revenue to the central station. If the consumer can be persuaded to accept a light requiring a little more energy or a little more gas, it is natural to suppose that the central station and the gas company would not be opposed to it, and if by the use of that slight addition individuality in a lighting installation can be established, the consumer, too, will be satisfied.

Mr. C. O. Bond: A new angle from which to view this question of recommended intensities of illumination should be acceptable. If there is anything which it is important for us to look at carefully when buying, it is our food; yet according to this table when we buy food we do so under 0.8 foot-candle illumination, but if we wish to purchase clothing, the proper selection of which is less directly connected with our health, we may do so under a much greater and satisfactory illumination. This point of view might well be emphasized; in dealing with illumination, we might show a greater regard for the hygienic requirements.

Mr. A. H. Keleher: This paper is very valuable to the contractor and commercial lighting man on account of having the watts per square foot given so clearly. I have found that a value of about one watt per square foot will do almost anywhere and no one will know the difference.

There is one feature to which the paper has not given consideration and that is the esthetic. As a rule I am more often given to the practical than the esthetic. In foreign lands, however, there is a much greater field for the esthetic than for the practical. We are so far ahead of foreign practise to-day in the scientific application of illumination that we have not a great deal to learn in that respect from our European colleagues, but when it comes to artistic effect, we know practically nothing. When I say this I am speaking of the average store lighting installation. I just wish to call attention to the lack of artistic installations for example on Broadway, New York. There is an absolute sacrifice of the artistic. In France the fixtures used are beautiful. In South America, they pay a great deal of attention to the artistic appearance. It is a shame that more study is

not given to the fixture beauty here, and the reason for it is because the people do not require it. I believe one could get the foot-candles and the artistic effect as well if the members of the Society would give due weight to both of these important features.

MR. M. H. FLEXNER: The Commonwealth Edison Company of Chicago has recently inaugurated an illuminating engineering department to handle its illumination business. This department is educating both the large and small consumer to the meaning and value of good illumination and has attempted to handle each case individually. So far it has succeeded in doing this. The solicitors are assisting materially in this work; they have been educated in the use of proper reflectors and correct installations.

I take exception to the paper just presented because I do not believe an average or recommended wattage per square foot basis is a good one for illumination work. Conditions alter cases and it is just as true of illumination work. I question if the haberdashery, which had a connected lighting load of 4.95 watts per square foot, could have been illuminated with the recommended wattage of 1.7 watts per square foot.

MR. R. B. ELY: The authors of this paper are to be congratulated on the great amount of work they have done in investigating the lighting equipment of some 800 stores, and for the tabulated data which gives information as to conditions as they are to-day. However, there are several points in this paper to which I wish to take exception.

On the first page the authors state "In the main, the lighting of the small store is not of sufficient importance to be treated separately or individually by the illuminating engineer" and it goes on to say that by using approximate rules, put in the hands of the central station or manufacturers' representative, with the aid of which he could intelligently design such lighting installations, a distinct step should be made in the advancement of the art of illumination. It seems to me that the illumination of the small store is of considerable importance because the aggregate number of small stores throughout our large cities represent quite a large percentage of our consumers, and each merchant who introduces either gas or electricity for the illumination of his store

is desirous of having his store superior to his competitor. Therefore, individual treatment in the design of the lighting equipment is desired, and the illumination of any store will, to a certain extent, be governed not only by the goods that are to be sold but by the location of the store and the illumination in that particular locality. The installations investigated were evidently good, bad and indifferent. This is evident from the wide range of watts per square foot as tabulated for the different stores. All the places investigated were designed, no doubt, by electricians, the individual consumers and also by those competent to design a lighting installation. Therefore, an average taken from installations, some of which evidently provided insufficient illuminated (as must be the case in the clothing store where a minimum of 0.27 watt per square foot is quoted) and the maximum of 4.16 watts per square foot for a millinery store, which is rather high for the average small store and was evidently too brilliantly illuminated.

In trying to formulate a table of this character certain installations that are regarded as being too brilliantly illuminated, so much so as to show defects in the goods as quoted, should be eliminated, as should those which are insufficiently illuminated, in working upon an average for recommendations.

In each case the wattage recommended is close to the average of the class of installation investigated, the greatest variation being in excess of the average recorded for the haberdashery stores. For instance, in the table at the end of the paper, under the classification of delicatessen stores, a maximum of 3.36 watts per square foot compared with 0.37 watt per square foot as a minimum, and an average of 1.11 watts, are given. Inasmuch as all the installations investigated were of tungsten lamps, I would like to know why this large ratio of from 1 to 5 and 1 to 10 in the amount of wattage for the small store that was selected as being in the same class occurs. The recommendation states 1.1 watts per square foot.

Broadly speaking, the wattage recommended per square foot is somewhat high, judging from the practise in Philadelphia.

If the general recommendations as to the placing of light sources for all classes of stores tabulated were carried out, I

believe, a monotony in design would result. This result has been experienced to some extent.

Relative to the illumination of jewelry stores, the following paragraph occurs: "Direct light of high intensity should illuminate the counter. Lamps with intensive prismatic reflectors located in a row over the counters will accomplish the desired results." In this class of lighting the use of a greater number of small lamps is more likely to enhance the appearance of the jewelry than the larger units.

I believe it is more desirable to stipulate the intensity of illumination required under the classifications of the various stores in terms of foot-candles, and if the authors had taken foot-candle measurements of the intensity, there might have been a better average, because it is quite possible that some of the stores with a relatively high wattage per square foot, had, to a certain extent, decorative features that probably would not add to the general illumination to any extent, but were of value to the storekeeper from an esthetic standpoint.

MR. G. H. STICKNEY: It has been suggested that the authors might have given more attention to the artistic and individual treatment of lighting installations. Particularly in consideration of the classes of stores covered, I believe that the method of averages which was adopted will be very much more useful than any other treatment in assisting solicitors and contractors, by whom such installations are usually laid out. It will be noted that the paper covers only those features which could be averaged. It gives a reliable statement of the present state of the art and furnishes important data hitherto incomplete. It would not be practicable in such a paper to suggest individuality for each of the innumerable small stores throughout the country. That feature must, of necessity, be left to the individual taste of those responsible for each particular installation.

With reference to the relation to the mean values found and the values recommended, I will say that, to my knowledge, these values have been discussed with a number of experienced illuminating engineers, who have expressed their agreement with them.

MR. A. L. POWELL (communicated in reply): Regarding the suggestions that individual treatment be given each store, I

believe that one of the statements in the paper has been misinterpreted. In the opening paragraph this statement appears: "In the main, these are not of sufficient importance to be treated separately or individually by the illuminating engineer. Therefore, if a set of approximate rules could be put in the hands of the central station or manufacturer's solicitor, with the aid of which he could intelligently design such lighting installations, a distinct step should be made in the advancement of the art of illumination." From this, one can see that the authors certainly intend that the stores shall be treated individually by the salesmen on the job, but our method of handling the subject, as given in the paper, rather precludes the presenting of individual methods here.

In the foregoing discussion a statement was made that "good, bad and indifferent stores were included;" and it was suggested that every brightly illuminated and every dimly lighted store be eliminated. This does not appear to me to be a desirable method of obtaining an average.

Objection was made to the monotony of design. Mr. Stickney has very well covered this point by mentioning the fact that each salesman will have more or less individuality which he will put into play.

Another criticism raised was the fact that the foot-candle readings should be taken. Considering the number of stores investigated, the amount of time required to make a fair test in each of the stores would be beyond all reason. However, those conversant with the various types of equipment mentioned know that the effective lumens per watt on a horizontal plane, with ordinary hanging heights and proper spacing, range from approximately 3.4 to 4.5 under average conditions, and it is therefore easy to compute with a reasonable degree of accuracy, the resultant illumination. The fact that in a large number of cases the side wall illumination is of utmost importance also complicates the situation. A number of speakers have laid great stress on the artistic and esthetic side. We would have been only too glad to have considered this, but the type of installation we had in mind is located in a store whose margin of profits on its sales is so small that efficiency of lighting is the primary consideration, provided such is obtained without injurious or deleterious effects. This fact in my mind also justifies our omitting the considera-

tion of the indirect system which one speaker thought would soon be adopted almost universally in this field of lighting.

DISCUSSION BEFORE NEW YORK SECTION.

MR. G. H. STICKNEY: Attention has been called to the effect of the height of ceiling on the quantity of light required, the speaker quoting an example of club room lighting. While undoubtedly in club rooms the variation of ceiling height would be sufficient to affect the amount of power and arrangement of lamps to a considerable extent, the experience of the authors confirms my own, that, in store lighting, the range of ceiling heights is quite narrow, and within these limits the variation in ceiling height would have practically no effect on the approximate watts per square foot. Likewise as to the color of walls—in this class of stores there is not as wide a variety as might be expected offhand; stores of a class generally run somewhat alike. It might have been practicable to have mentioned in the paper that in very dark stores a somewhat higher wattage per square foot would be demanded than for very light stores.

The height of ceiling and color of walls are only two of the variables which there was temptation to cover in the paper, but which were omitted for the sake of simplicity, in the belief that they would not add to the value of the data given, enough to warrant the complication which they would introduce.

Another speaker has mentioned the personal element introduced by the nationality of the proprietor of the store. It was observed in collecting these data that this was an important element, and that the amount and quality of illumination depended, to a considerable degree, upon the characteristics of the proprietor. While this information is on file, it will readily be understood that there might be considerable objection to its publication, at least from the standpoint of policy.

A considerable amount of show-window data was collected, but, as this did not conform naturally to the classification of the stores and as it is a subject of sufficient importance to require separate treatment, it was not included.

Reference was also made to the suggestion under Art Stores, of the desirability of putting in a relatively high intensity of

light on the walls. This is indicated in fig. 1 of the paper, in which it will be noted that the important surfaces to be illuminated are largely those which lie more or less nearly in the vertical plane and hence require a relatively high horizontal component of the light, for their effective illumination. The cut shows that many of the pictures hung on the wall are tilted forward. This is presumably to eliminate objectionable reflection of the light source when viewed by the customer.

The purpose of giving quantitative values in watts per square foot, rather than in foot-candles, was two-fold; first, this unit is much more readily understood by those responsible for lighting installations of this class (not only by store proprietors and contractors by whom the work is done, but even solicitors who sell energy, lamps and equipment) and they will receive very much more benefit from the values expressed in these terms than if the foot-candle unit were used. The second reason for the use of the watts per square foot value was that it would not have been practicable, under the circumstances under which this data was gathered, to have made foot-candle illumination tests, and certainly to have made such measurements as would have indicated the average conditions. Further, question would have been raised as to whether the measurement should be made in foot-candles averaged throughout the room, on the counters or walls, and any such data would not have been of as great general value as the simple measure of the total flux of light in terms of watts per square foot.

Another element of value in this data is the large number of stores of each class which were inspected, thereby insuring an average which has some meaning. It must be realized that each visit must, from necessity, be made short, and from the start a considerable amount of suspicion was encountered on the part of the proprietors, who were inclined to require a considerable amount of explanation before giving permission to take the data. This was gotten around by sending two men, one of whom made the explanation to the proprietor, while the other noted down the different items listed on the second page of the paper.

REPORT OF THE ILLUMINATION COMMITTEE OF THE ASSOCIATION OF IRON AND STEEL ELECTRICAL ENGINEERS.*

In the last few years, because of the introduction of new types and sizes of lamps, the application of engineering principles to the use of lamps and the necessity of studying from an engineering standpoint the problems peculiar to the illumination of iron and steel works, the Association has given considerable attention in its conventions to the subject of illumination.

In 1910, illumination sessions consisted of brief talks by manufacturers on the merits of their individual products. These talks were closed to competitors. In this convention, Mr. G. H. Stickney gave a general talk on the engineering phases of the subject, which now appears in the *Proceedings*.

In 1911, a day was devoted to illumination. Four papers were read as follows: "The Light for Safety," F. R. Fortune, Cooper Hewitt Electric Company; "Special Lighting for Steel Mills," H. M. Gassman, Tennessee Coal, Iron & R. R. Co.; "Iron and Steel Works Illumination," C. J. Mundo, General Electric Co.; "Some Features of Good Steel Mill Illumination," Ward Harrison, National Electric Lamp Association. The 1911 session was open and papers were subject to general discussion.

In 1912 a day will be devoted to illumination. The following papers will be read: "The Incandescent Lamps in the Steel Industry," Ward Harrison; "Curves and Data for Illumination Calculations," C. J. Mundo; "Modern Illumination in the Iron and Steel Industry," C. E. Clewell. The sessions will be open as in 1911, and the papers will be discussed.

Following the 1911 convention, the present illumination committee was appointed to study and report on the needs of the iron and steel works engineer with respect to the subject of illumination. It was recognized that much information exists which is helpful to the engineer in handling his lighting problems. But the whole science is in a stage of development and much remains

*A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

to be done toward the solution of industrial lighting problems in general.

In addition to the special points discussed in this report, it will be seen that an important need of the mill engineer is for data in such shape that their authoritativeness and value may readily be recognized and such that they may be put to use by a man whose work ranges over a comparatively wide field and who has hardly time to become a specialist in a particular field. With the data now available and with experience gathered through handling a wide range of problems, the illumination expert can make an accurate comparison between lamps and design lighting installations, so that under given conditions a desired illumination result will be obtained. The data, however, at the command of the expert are not complete. The mill engineers, as a general rule, must solve, or at least must be in a position to solve, his own problems as they come up without excessive labor or study.

The mill engineer in the satisfactory solution of a lighting problem is interested first in the special requirements to be met; second, in a comparison of commercially available illuminants; and third, in the correct application of the illuminants.

A certain amount of work has been done on the special requirements to be met in iron and steel works illumination. Much of the information at present available on industrial lighting is applicable, but there is a wide field for the study of problems peculiar to the processes of the manufacture of iron and steel. In the endeavor to raise the standard of lighting in steel plants, minimum satisfactory intensities have been obtained by test and are now on record in the *Proceedings*[1] of the Association.

It is recognized that a rough comparison of the size of lamps without regard to the utilization or distribution of the light may be made on the basis of the mean lower hemispherical candle-power, or the downward lumens (mean lower hemispherical candle-power $\times 2\pi$). The former comparison is on the basis of the mean candle-power in a downward direction and the latter on the basis of the quantity in lumens of the light projected downward. To take utilization and distribution into consideration, the horizontal illumination curve is necessary. In order to compare lamps on the basis of average performance

[1] "Iron and Steel Works Illumination," C. J. Mundo, *Proceedings A. I. & S. E. E.*, 1911.

the candle-power deterioration curve is also essential. Comparison of lamps on the basis of *average* performance throughout the life or trim, in the case of arc lamps, was urged in a paper[2] which appeared in the June, 1911, TRANSACTIONS of the Illuminating Engineering Society. The candle-power distribution

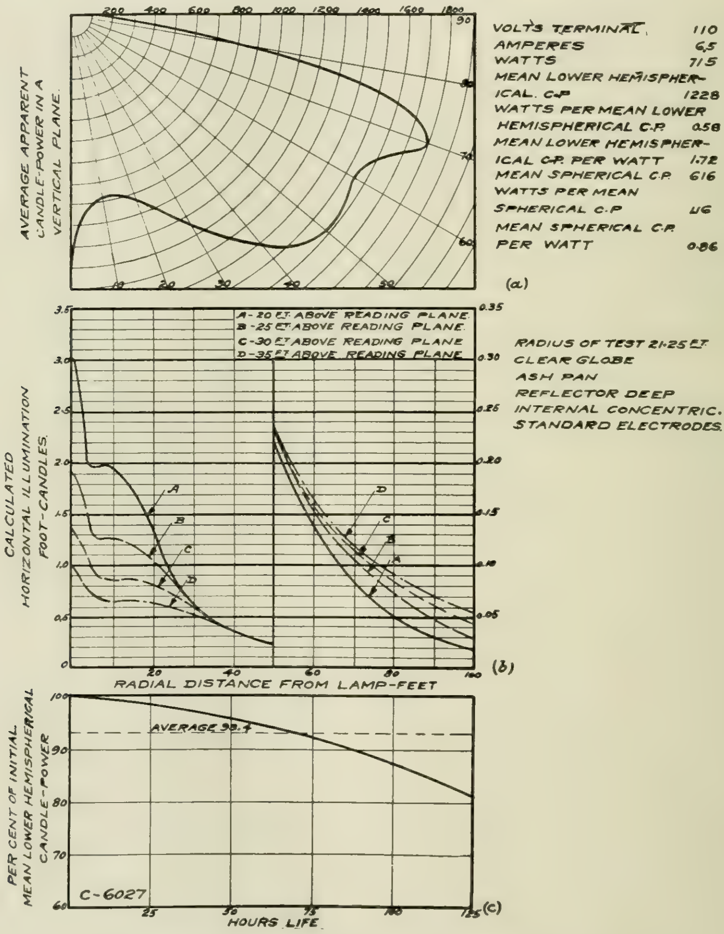


Fig. 1.—A convenient record of performance data of a 6.5 ampere direct-current multiple luminous arc lamp.

curve, the horizontal illumination curve, and the deterioration curve required for a complete comparison of lamps can con-

[2] "Notes on Comparison of Illuminants," S. W. Ashe.

veniently be published on one sheet as shown in fig. 1. These curves can be made to serve the same purposes as the motor characteristics curves shown in fig. 2, the use of which in the comparison and selection of motors for crane or hoist service is generally well known.

It has been found convenient to speak of the deterioration in candle-power which takes place in lamps as consisting of inherent deterioration, or that which will take place under laboratory conditions, and of acquired deterioration, or that which is due to dust and dirt acquired under conditions of service. Until

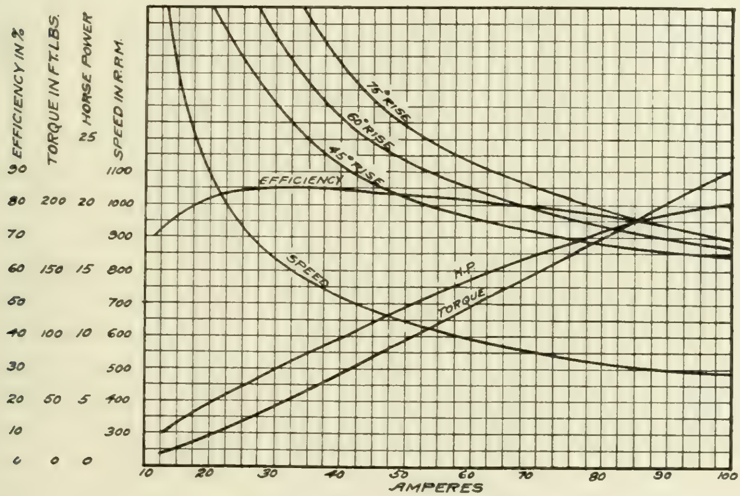


Fig. 2.—Motor characteristic curves.

data on acquired deterioration are available comparison of lamps with respect to acquired deterioration must be made with reference to the mechanical construction of the illuminant.

The correct utilization of lamps involves the lamps themselves, but especially the illumination results given by the lamps. Sufficient intensity, evenness of distribution and freedom from glare and from objectionable shadows are essential to a good lighting installation. Two principal methods of laying out industrial lighting installations to secure a desired result are in use, namely, (1) the point-by-point method and (2) the effective lumens per watt method.

Out of the point-by-point method has come the plotting of horizontal illumination curves and their often times laborious use to determine the number, size and location of lamps required. Even illumination curves, however, are too infrequently met with, although many manufacturers issue candle-power distribution curves and tables of constants for the calculation of the horizontal illumination.

The effective lumens method involves only a simple calculation, but data for the use of this method have not been fully worked out especially for the use of lamps in high buildings. This method gives no idea of the evenness of the illumination intensity or of the adequacy of the intensity at any point. This method is most useful, however, in conjunction with the point-by-point method to obtain the number of lamps which should be used. The intensity at any point or the evenness of the illumination can then be checked by means of the illumination curve.

At present for the high candle-power lamps, which on the basis of correct utilization require to be hung at the greater heights, and for the lower candle-power lamps used at the greater heights, the engineer is obliged to depend on the horizontal illumination curve alone.

Constants (k) applying to the above conditions for substitution in the formula $N = \frac{S \times E}{W \times K(1 - D)}$ where N equals the number of lamps, S the area to be illuminated in square feet, E the average illumination intensity in foot-candles, W the rated terminal wattage of the lamp, K the effective lumens per watt (rated) at the lamp terminals, and D the average deterioration in the illumination from the lamps, would greatly aid the mill engineer and lead to a closer study of illumination requirements. A layout may be quickly made with the number of lamps thus obtained and a check made by means of the horizontal illumination curve for evenness of distribution and intensity at any point.

The factor D in the equation brings up the important question of deterioration. A large amount of investigation is involved in the satisfactory settlement of this question. A certain amount of data has been published on the depreciation or deterioration of candle-power of lamps, under laboratory conditions.

Data on acquired deterioration must be obtained by means of illuminometer tests under conditions of service. Such tests if carefully made and conducted over a period representing the life of the lamps, can be made to check the inherent deterioration. Such tests and data will show clearly the necessity for

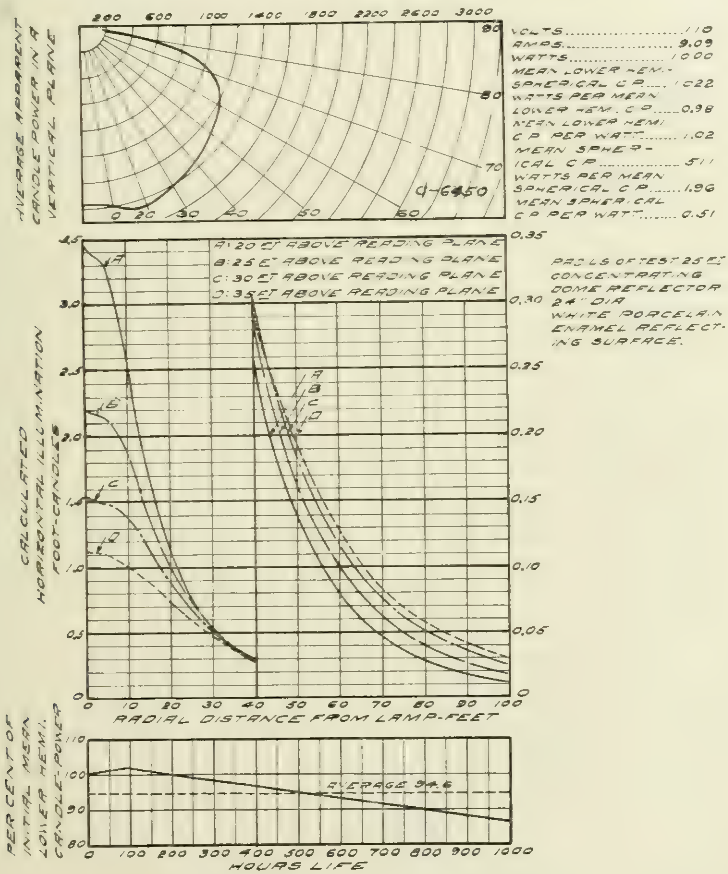


Fig. 3.—A convenient record of data on the performance of four 250-watt multiple tungsten lamps equipped with a dome reflector.

continued and thorough upkeep of lighting systems, and the frequency with which lamps should be cleaned to avoid excessive deterioration.

In connection with illumination data furnished by manufactur-

ing companies, it is suggested by the committee that much doubt as to the value and usefulness of the material would be eliminated if data sheets were to contain full information as to the authority for the data, date of tests, and so forth. The candle-power curve of an illuminant is likely to be modified by a change in globe equipment, by a change in electrode equipment, by frosting of the bulb, etc. The committee, therefore, recommends that on all curves the following data be included by manufacturers and required by engineers:

1. Date of test.

2. Authority of test.

3. Full equipment of lamp, such as reflector, electrodes, globes, etc.

4. Total per cent. absorption by globe equipment.

7. Kind of current: a. c. or d. c.

8. Frequency if a. c.

9. Series or multiple operation.

10. Terminal watts.

11. Terminal volts.

12. Terminal amperes.

13. Arc volts if an arc lamp.

14. If an incandescent lamp, total lumens[3] per watt or watts per horizontal candle-power at which test was made.

On candle-power curves:

1. Radius at which test was made.

2. Total lumens or mean spherical candle-power.

3. Downward lumens or mean hemispherical candle-power.

4. If tests are made in several vertical planes, and the average taken, this should be indicated, and the position of the planes shown diagrammatically.

5. If candle-power or lumens per watt are given, these should be based on terminal and not on arc watts.

It is recommended by the committee (1) that in judging lamp size the mean lower hemispherical candle-power or the downward lumens be used, in conjunction at least with the average inherent deterioration of the lamp during the life or trim. The liability of the lamp to acquire deterioration can be judged on

[3] Total lumens equals mean spherical candle-power times 4π.

the basis of the mechanical construction until acquired deterioration data is available.

(2) That the illumination curve for the height at which the lamp must be used be employed to check the evenness of the illumination from the lamp and the utilization of the light.

(3) That manufacturers be encouraged to submit candle-power distribution, illumination and deterioration curves on illuminants.

(4) That manufacturers be urged to submit constants or spacing tables for the use of lamps.

(5) That illumination tests be encouraged by the members for the purpose of obtaining data on deterioration.

(6) That the association coöperate with the Illuminating Engineering Society by encouraging such tests and by presenting from time to time for discussion and solution, the problems of the members.

Illumination Committee,
H. H. LAUGHLIN,
H. M. GASSMAN,
R. TSCHENTSCHER,
JAMES FARRINGTON,
B. W. GILSON,
C. J. MUNDO, *Chairman.*

DISCUSSION.

MR. WARD HARRISON: I believe that the presentation before this society of a report such as has just been read is significant. Men in the allied professions, engineers, architects and occulists, have in many cases been slow to recognize the assistance which the illuminating engineer is able to render them; in this case, on the other hand, we have an Association representing one of our chief industries and composed of engineers of high standing, who have expressed a desire to co-operate with us and who have recognized that we can be of assistance to them. The Illuminating Engineering Society should see to it that they receive all that is within its power to give.

The report is devoted chiefly to setting forth definitely what data the members of the association are desirous of obtaining at

this time. On the second page we read that the data available on lamps and lighting installations are not complete, that the material now at hand is not in proper form to be utilized readily by the mill engineers and that the important need is for data in such shape that their authoritiveness and value may be readily recognized and that they may be put to use without extensive investigation or study by a man whose work ranges over a comparatively wide field.

The increasing need for information of this character was pointed out in a paper "Analysis of Performance and Cost Data in Illuminating Engineering," presented before this Society last year at the Chicago convention. We may be certain that the Association of Iron and Steel Electrical Engineers is not the only society from which requests of this nature are to be expected. Unfortunately the TRANSACTIONS of our society contain little of such material; the statement has even been made that it is so extremely difficult, if not impossible, to arrange for the presentation of reliable data of this sort that the Society had better let the matter drop. At present, however, the iron and steel engineers are actively interested in this subject and naturally enough look to the Illuminating Engineering Society for cooperation and assistance. If we are able to help them in this matter, they will without question be more receptive to suggestions from illuminating engineers in regard to the other vital factors determining the most desirable lighting installation, which are the especial province of the practitioner in this field and which are likely to be thought worthy of scant attention by engineers who give illumination questions but a small part of their time.

The day of the man who refuses to tell the whole truth about his product is rapidly passing in the lighting industry. Some of the iron and steel engineers have a very effective means of dealing with such persons, for when it comes to choosing an illuminant, they simply refuse to consider any unit upon which a manufacturer is unwilling to submit complete information. Mr. Pierce's paper of yesterday is deserving of the highest commendation. He has opened the way for a discussion of depreciation factors and other practical data; and I believe that other lamp manufacturers will be glad to fall in line. It would seem

fitting that, as in this case, such data should first be presented before the Illuminating Engineering Society.

Mr. G. H. Stickney: Mr. Harrison spoke with regard to acquired depreciation. That is one of the things in which the Iron & Steel Electrical Engineers can give us useful data, as their plants furnish excellent laboratories for that kind of research.

With regard to the usefulness of these curves and the danger of their misinterpretation, I think perhaps some of us are not quite familiar with the methods followed by the steel engineers. They have not judged the performances of lamps by mere inspection of curves, but have used the point-by-point method to a considerable extent. In some problems they have calculated the illumination in advance and then checked the values with illumination measurements of actual installations.

The results of tests conducted in a number of mills was reported at the 1911 convention of the Association of Iron & Steel Electrical Engineers. This was one of the most thorough investigations of lighting problems in actual installations of which I have known and is well worth looking up. The cordial co-operation which we are securing from this organization is bound to be mutually beneficial and we certainly appreciate their courtesy in submitting this report.

Mr. R. F. Pierce: I quite agree with Mr. Harrison in all that he has said in regard to the presentation of complete data which will be really useful to the engineer in evaluating the efficiency of each particular type of unit for particular service, and I believe that the form of tabulating such data, as given on the third page of the report, is an excellent one.

In this connection, there is one thing that occurs to my mind. I have my doubts as to the usefulness of the distribution curve for conveying an idea of the lamp's suitability as far as its use in service is concerned; that is to say, the average engineer of a plant in viewing a distribution curve, while he may be conscious of the fact that the flux represented by candle-powers at different angles is not the same at each angle and he may try to allow for it mentally, he may not be able to form a very definite conception of the amount of light in the different zones. Would it not

be better to furnish also polar *flux* distribution curves? This would give a curve the form of which would be indicative of the *amount* of light in different zones. The ordinates might be made proportionate to the squares of the quantities so that the lumens in any zone could be read by the use of a planimeter, and a glance at a curve would give a good idea of the total light in any zone. This would have the same advantages for calculations by the point-by-point method as the ordinary distribution curve; only a different set of constants would be needed. It would be a curve different in shape from the ordinary distribution curve, of course, but I have prepared many curves along this line and have found them very useful. While the ordinary curves may show a small apparent difference in the distributions of two units, a curve plotted according to the latter system has showed up very distinctly defects in the design of the reflector or the distribution of the unit which were not apparent in the ordinary distribution curve.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VII. NOVEMBER, 1912. NO. 8

COUNCIL NOTES.

The council held its regular monthly meeting November 15, 1912, in the general offices of the society, 29 West 39th Street, New York. Those present were Messrs. V. R. Lansingh, president; H. E. Ives, Geo. S. Barrows, C. J. Russell, L. B. Marks, A. J. Marshall and Preston S. Millar, general secretary.

Reports were received from the secretary and the following committees: finance, advertising, section development, and reciprocal relations with other societies.

The committee on illumination primer, Mr. L. B. Marks, chairman, submitted a report on the distribution of the primer—"Light: Its Use and Misuse." The report showed that the society had distributed free 5,378 copies and sold 3,365 copies. It was also stated that the primer had been extensively advertised in the trade journals of this country and abroad. The publication of a second edition of the primer was authorized.

A report was received from a special committee which had been appointed to consider the advisability of establishing a section of the society in Cleveland. The committee did not favor the formation of a section in the latter city but recommended that a section including several of the large cities in the middle west and in the great lake region be established. It was proposed that this section should hold three or four meetings during a season, each one taking a whole day and being held in a different city. The council approved the formation of such a section. The work of organization will be undertaken shortly.

A by-law permitting the sale of the page facing the last page of text and the inside cover page of each issue of the TRANSACTIONS for advertising purposes was given a first reading.

The following committee was appointed to consider factory lighting legislation: L. B. Marks, chairman; Preston S. Millar,

M. C. Whitaker, Ellice M. Alger, W. H. Gartley, G. H. Stickney, and H. E. Ives. Additional appointments to the committee will probably be made later.

SECTION ACTIVITIES.

CHICAGO SECTION.

The Chicago section held a meeting November 13 in the Western Society Auditorium. Mr. Wm. A. Richardson, assistant chief engineer of the Federal Building, Chicago, presented a paper entitled "Post Office Mail Case Lighting."

For the rest of the season the following program of papers has been arranged:

December: "Industrial Lighting," by Mr. Ward Harrison, Engineering Department, National Electric Lamp Association, Cleveland, Ohio.

January: "Indirect Illumination as Applied to General Offices," by Mr. T. H. Aldrich, National X-Ray Reflector Company, Chicago, Ill.

February: "Influence of Colored Surroundings upon the Color of Useful Light," by Mr. M. Luckiesh, Physical Laboratory, National Electric Lamp Association, Cleveland, Ohio.

"Some Applications of Illuminating Engineering to the Conservation of Eyesight," by Mr. F. A. Vaughn, Consulting Engineer, and Dr. Nelson M. Black, Ophthalmologist, Milwaukee, Wis.

"Gas Illumination." Author not selected.

This meeting will be held in Milwaukee in conjunction with the Milwaukee Electric Show.

March: "Hospital Lighting," by Mr. Meyer J. Sturm, Architect, Chicago, Ill.

April: "Light, Shade and Color in Architectural Effects," by Mr. Bassett Jones, Jr., Consulting Engineer, New York.

May: "Up-to-date Gas Illumination." Author not selected.

June: "Some Phases of Illumination and Eye Strain," by Mr. Arthur J. Sweet, Commercial Engineer, Holophane Works of General Electric Co., Newark, Ohio.

NEW YORK SECTION.

The New York section held a joint meeting with the New York companies section of the National Electric Light Association

November 18 in the Edison Auditorium, 44 West 27th Street, New York. Mr. Preston S. Millar presented a paper together with a series of demonstrations on lighting effects.

The following program has been announced by the New York section board of managers:

December 12: Joint meeting with the Art and Trades Club at which Mr. George Leland Hunter will present a paper on "Color."

January 9: A joint meeting with the National Commercial Gas Association.

February 13: A joint meeting with the Municipal Art Society.

NEW ENGLAND SECTION.

The program of papers and meetings that has been announced tentatively by the New England section board of managers is as follows:

December: "Head Lights, Lighthouses and Lenses," by an inspector of the United States Government.

January: "Vision and Defects of Vision."

February: "The Light of the Stars."

March: "New Types of Arc Lamps."

April: "Methods of Light Best Adapted to Reinforce Daylight at Dusk."

May: "Photographic Lighting."

PHILADELPHIA SECTION.

The regular meeting of the Philadelphia section was held at the Franklin Institute, Friday evening, November 15, 1912. Preceding the meeting there was a dinner at Hanscom's restaurant and subsequently an inspection of the indirect lighting of the Curtis Publishing Company's building at the northwest corner of Sixth and Walnut Streets. At the meeting the lighting of the latter building was discussed by Mr. G. H. Swanfeld.

PITTSBURGH SECTION.

The following program of meetings and papers has been announced tentatively by the board of managers of the Pittsburgh section:

December:	"Store Illumination." This subject will be presented by a representative of the Holophane Works of the General Electric Company.
January:	"Street Lighting," by Mr. C. E. Stephens.
February:	"Gas Illumination."
March:	"The Incandescent Lamp in the Central Station Business."
April:	"Some Phases of Railroad Illumination."
May:	"Physiological Aspects of Illumination."

Preceding each meeting Prof. H. S. Hower will give a short elementary lecture on light. One joint meeting is being arranged with the Pittsburgh branch of the American Institute of Electrical Engineers.

THE VALUE OF ILLUMINATING ENGINEERING TO SOCIETY.*

BY V. R. LANSINGH.

I. THE NECESSITY OF ILLUMINATING ENGINEERING TO SOCIETY.

From the time of the advent of man on earth to the time when the steam engine began to be extensively applied to industry, the amount of work demanded of the average eye was practically constant and well within the capacity of the eye. Of course there were scholars and clerks engaged in excessive visual work, as well as artisans in fine metal work, laces, etc., but they formed a relatively insignificant portion of the total population. Agriculture was the great industry. Even in the city, there were comparatively few occasions in the daily life of the average citizen for reading, writing or similar close work.

In this connection, it should be remembered that "eyestrain" means a strain of the muscular system of the eye and that these muscles are all relaxed at visual distances greater than approximately twenty feet. In other words, the eye is practically resting when we look more than twenty feet away.

Since the application of steam to industry, the daily life of the average man has undergone a radical change, among other factors involved being a tremendous increase in the amount of close visual work. This increase in visual work has arisen, directly or indirectly as a result of industrial development, from the following sources:

(a) Directly, as involved in the greatly increased proportion of people engaged in manufacturing work itself. The processes of manufacture usually involve close visual work.

(b) Directly, as involved in the vastly increased proportion of clerical work resulting from industrial development.

(c) Indirectly, as involved in the great extension of primary and secondary education.

(d) Indirectly, as involved in the universal ability to read and the cheapening of books and newspapers, so that the average man, as a matter of choice, does much reading.

* Presidential address delivered before the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Canada, September 16-19, 1912.

The increase in the amount of close visual work has necessarily been accompanied by a proportionate reduction of the periods of visual rest, when the eye is looking at distances greater than twenty feet. This vast increase in close visual work would in itself present a difficult and serious problem in public health even if ideal conditions of illumination had been universally maintained. To the contrary, however, changed social conditions have involved a greatly increased congestion in the housing arrangements for industrial and clerical work. This congested housing has tended to result in less satisfactory daylight lighting than would otherwise have been the case. It is not always realized that the illuminating engineer has an important field of future usefulness in treating problems of daylight as well as problems of artificial illumination.

Again, changed social conditions have required that work be done during the fading hours of daylight in the winter season, and also by night. And, naturally, much of the increased reading of books and newspapers must be done by night. The character of illumination on the work and of surrounding visual conditions may greatly multiply or minimize the strain incident to long continued close visual work. Broadly stated, therefore, the function of the illuminating engineer in society is to determine and to apply to actual practise such visual conditions as will minimize the strain incident to the vastly increased amount of visual work.

From the considerations already set forth, it is evident that the function of the illuminating engineer and his relation to society present two broad aspects: the hygienic and the economic. In addition to these there is still a third aspect of importance—the esthetic.

II. THE HYGIENIC VALUE OF ILLUMINATING ENGINEERING TO SOCIETY.

Vision is one of our most precious faculties. Its loss is a calamity second only to death. Its impairment means, to the individual, physical discomfort, curtailment of such pleasures as reading, disbarment from many lines of work, and decreased earning capacity in others. Nor, when vision is impaired, is it practicable to effect a cure. The disability is life-long, and is

apt to be of increasing seriousness. A cure could be effected, but only by the patient reverting to semi-savage conditions and living in the open country, never reading, nor doing any close work, for a period of years. This is impracticable. Therefore the ophthalmologist devotes himself to the alleviation, not to cure, and gives us eye-glasses, which, if we do not further abuse our eyes, will entirely check or greatly retard the advance of the disability. Eye-glasses, on the one hand, in no sense cure the impairment of vision; nor, on the other, do they save the eyes from the disastrous results of further abuse. The almost universal ignorance of even the well educated man as to the causes of impaired vision and as to the nature of proper visual conditions gives increased weight to the moral responsibility and social importance of the illuminating engineer.

The hygienic value of illuminating engineering particularly affects society in: (a) the office; (b) the factory; (c) the home; (d) the school room. In these four classes of service, the hygienic importance of illuminating engineering far outweighs the esthetic or economic importance.

The office: Excellent progress has been made in bringing about a general condition of good office lighting. Yet probably not over twenty per cent. of the offices in the United States are illuminated by night as well as we know how to illuminate them under the present best state of the art. There is considerable room for improvement in the daylight illumination of offices, especially in the congested districts of our larger cities.

The factory: Great progress has been made in the last fifteen years in the daylight illumination of our factories. The movement for adequate artificial illumination of our factories, however, has only begun to show strength within the last year or two. The present condition of artificial illumination of factories leaves much to be desired, but signs of large future improvements in this direction are not wanting.

The home: Adequate lighting in the home for reading and other close work is the great exception rather than the rule. However, the general education of the public on the subject of illumination is beginning to arouse the individual, here and there, to the importance of adequate lighting in the home.

The schoolroom: The artificial lighting of school rooms is as a rule bad, but in some of our larger cities much good work has been done, especially in Boston, New York and St. Louis. Daylight lighting is also not infrequently bad. General interest in this subject, however, is beginning to be apparent. It is certainly a hygienic consideration of the very highest importance not to handicap our children at the very outset of life with impaired vision.

There is really no monetary value that can adequately compensate the individual for impaired vision. We should, therefore, put the adequate illumination of the office, the factory, the home and the school room as the highest responsibility and the most important work of the illuminating engineer. If in these four classes alone the illuminating engineer can bring about a general condition of adequate illumination, we may confidently expect that, in spite of the excessive amount of close visual work incident to modern social conditions, the prevalence of eye-strain will be materially reduced.

III. THE ECONOMIC VALUE OF ILLUMINATING ENGINEERING TO SOCIETY.

The economic value of illuminating engineering to society may be summed up under five general heads:

(a) Increased quantity of work per man which adequate illumination makes possible without added fatigue.

(b) Improved quality of work resulting from adequate illumination.

(c) Decreased cost of artificial lighting, due to intelligently employing the light so as to produce the results desired.

(d) Decreased liability to bodily injuries, such injuries, representing economic waste.

(e) Decreased number of cases of defective vision, such defective vision impairing the economic value of the individual to society to a greater or less degree.

By adequate lighting is here meant light of sufficient quantity, intensity and direction to enable one to see the work clearly and distinctly without eye-strain.

(a) Increased quantity: Inadequate lighting makes necessary additional and time-consuming work; as, for instance, when a

clerk has to carry a record from its file drawer to some better location in order to read it. Inadequate lighting also greatly decreases the rapidity with which clerical or manufacturing work is performed. Inadequate lighting also materially increases the prevalence of such bodily disorders as headache, etc., thus decreasing the working capacity of the individual. Actual experience wherever records have been kept has demonstrated that the substitution of adequate lighting for inadequate has materially increased the quantity of work performed. Moreover, the cost of adequate lighting, including the energy cost, depreciation and interest on investment, and maintenance cost, average less than two per cent., and practically never exceeds five per cent. of the clerical or industrial worker's wage. The cost of even grossly inadequate lighting will usually be at least one-half this amount. Adequate lighting has, therefore, only to save about five minutes of the worker's day to amply pay for itself.

(b) Improved quality: Actual experience has shown that the amount of spoilage and of damaged and lost material is very appreciably decreased by the substitution of an adequate lighting installation for an inadequate one. In departments or offices where disorder has been the rule under an inadequate lighting system, the installation of an adequate lighting system has invariably led to keeping the material in better order, with a resultant increase in departmental efficiency.

(c) Decreased cost of lighting: The operating cost is very decidedly the major element in the total cost of lighting. Now, the operating cost depends upon three factors: (*1*) the efficiency with which the light is generated; (*2*) the efficiency with which the light is transmitted from the point where it is generated to the point where it is used for illuminating the work; (*3*) the efficiency with which the lighting effects are translated into terms of visual sensation—in short, eye-efficiency.

(*1*) The efficiency with which the light is generated depends upon choosing an efficient light source, such as the tungsten filament lamp rather than the carbon filament lamp, or the mantle gas lamp rather than the open flame gas burner.

(*2*) The efficiency with which the light is transmitted from the point of generation to the point of use depends upon the use

of efficient and correctly designed reflectors and globes; upon the color and reflection characteristics of the ceiling; and, to a small degree, upon the color and reflection characteristics of the walls and floor. In street and other out-of-door lighting, the last two factors, of course, entirely disappear.

(3) The efficiency with which the eye translates external lighting effects into terms of visual sensation depends upon many factors. Of these, one of the most important is the degree to which the illumination upon the work is diffused. Then comes the degree to which the surface of the work avoids specular reflection. Next comes the amount of extraneous light, not reflected from the work, which enters the eye, such light coming either directly from the light units or by reflection from the walls. The foregoing constitute the three major factors affecting the efficiency of the eye. The extremes of contrast to which the eye, during use, is frequently exposed is also a factor. The nearness of approach to monochromatic light is, in some special types of service, a factor of practical importance. The intensity of illumination, whether too high or two low, does not directly affect the efficiency of the eye, but may, through the medium of fatigue, affect eye-efficiency to a very important degree.

It is interesting to note that in the earliest beginnings of illuminating engineering, efficiency of light generation was the efficiency factor chiefly considered. Later, roughly corresponding to the decade 1900-1910, the importance of efficiency of light transmission was most emphasized. During the past year or two there has been a marked and growing tendency to give great weight to the importance of attaining such illumination conditions as will permit the eye to operate at high efficiency.

(d) Decreased liability to bodily injuries: It is an established fact that a considerable proportion of industrial accidents are the result of inadequate light. The majority of foot, automobile and other traffic accidents by night are also the results of inadequate lighting. Sufficiently adequate lighting to avoid accidents can usually be laid out by the illuminating engineer so as to involve no greater operating cost and only slightly greater installation cost than that of the inadequate installation.

(e) Decreased number of cases of defective vision: Only

a moment's consideration is required to show that the annual economic loss due to defective vision is enormous. A conservative estimate would place at 500,000 the number of cases in the United States of defective vision arising from the excessive use or abuse of the eye Assuming an average value to society of $600.00 per individual per year, and further assuming, as we safely may, that the productive capacity of the individual, even when his eyes are fitted with eye-glasses, is reduced ten per cent. by defective vision, we have an annual economic loss of $30,000,000.

It is not claimed that adequate illumination, both daylight and artificial, will remove all danger of visual defects caused by the use of the eye in meeting the demands of modern society. But it is believed that a very general condition of adequate illumination would reduce by considerably more than one half the number of cases of such visual defects.

The economic value of illuminating engineering I have discussed primarily from the standpoint of its value to society at large. It should be pointed out, however, that this economic gain would accrue in the largest measure to the benefit of the employer of clerical or industrial labor. Indeed the direct dollars-and-cents gain to the employer resulting from adequate lighting is so greatly in excess of the installation and operating costs, that, hygienic and humanitarian considerations aside, inadequate lighting is indefensible from the standpoint of selfish gain to the employer.

Besides the employer, almost every industry which directly serves the public will find a personal profit from adequate lighting, sufficient to many times repay the cost of such lighting. Extensive practical experience, not theory, stands sponsor for the fact that the business and profits of the merchant, of the gas or electric central station, and of the railroad are very materially increased by the employment of adequate illumination in all relations where these industries come into direct touch with the public.

The illuminating engineer has, therefore, an important field for economic usefulness to society second only to his opportunity for hygienic usefulness.

IV. THE ESTHETIC VALUE OF ILLUMINATING ENGINEERING TO SOCIETY.

The appreciation of the beautiful depends in largest measure upon the faculty of vision. It is obvious, therefore, that the conditions of illumination may greatly enhance or greatly mar objects of beauty. All literature bears tribute to this. To cite but one instance, Sir Walter Scott tell us:

> "If thou woulds't view fair Melrose right,
> Go visit it by the pale moonlight;
> For the bright beams of the gladsome day
> Guild but to flaunt the ruins gray."

The degree to which the face appears attractive or unattractive depends to considerable measure upon the way in which the room is lighted. Both the architectural beauty and the effect of solemnity of a church interior may be enhanced or ruined by the way in which it is lighted.

Light may also be employed as a source of ornament. A notable example of this is in the ceiling of the Allegheny County Memorial Building, Pittsburgh, Pa. Less notable examples are frequently seen in hotel lobbies, halls of public buildings, theatres, etc.

Light may be used as a painter uses his brush to bring out or to subdue the various elements of an interior which it is sought to treat as an artistic composition. This phase of the subject is of notable importance in the study of the illumination of the home. In the dining room, for instance, artistic requirements will be best met if the dining table is brightly lighted, while the rest of the room receives only a subdued general illumination. So in the living room, the artistic center, usually either the reading table about which the family group themselves, or the piano, would be emphasized over the rest of the room by brighter lighting, if a sense of artistic proportion is to be produced.

Before and since the advent of the illuminating engineer, some architects have realized and applied to practise the esthetic possibilities of light. There has, however, been far too great a tendency on the part of the architect to regard only the artistic possibilities of the light sources themselves, treated as ornaments, and too little a tendency to subordinate the light sources of the

artistic presentation, by means of a correctly balanced illumination, of the interior or exterior in question.

In the cases where the architect has fully grasped the possibilities of this new and broader conception of the application of light and illumination to esthetics, the illuminating engineer can properly defer to the architect in the matter of what results are to be achieved, and consider his own proper sphere to be that of advising how to achieve the results specified by the architect. But the question of light control in these present times, when the market offers so many different types of reflecting, diffusing and refracting media, is a highly technical one, which can be satisfactorily solved only by the specialist in illuminating engineering.

V. THE SUPPORT OF ILLUMINATING ENGINEERING BY SOCIETY.

The foregoing considerations clearly indicate the large need which society has of illuminating engineering, and of the illuminating engineer, to translate the principles of his science into practise. Unfortunately society has not yet appreciated its need to such an extent as to furnish anywhere near adequate support to the illuminating engineer.

At the outset it should be most emphatically stated that the day is past when the layman, however, well educated and intelligent can satisfactorily be his own illuminating engineer. Society must find some practical way of supporting the illuminating engineering specialist and of referring to such specialist its detailed problems of lights. The most obvious way would be to support a considerable body of consulting illuminating engineers. While we number in our organization a few notable exceptions which prove the rule, there are no present indications that society is willing to support such a body of consulting illuminating engineers.

Another way would be for the architect to employ the services of an illuminating engineer, and thus indirectly to place upon society the burden of supporting the latter. To day, however the architectural fraternity has, with a few notable exceptions, failed to recognize the important hygienic, economic and

and esthetic services which it lies within the power of the illuminating engineer to render.

To date the illuminating engineering, as a factor in society, has been chiefly supported by the manufacturing and the central station interests. This statement does not overlook the fact that there have been at least half a dozen consulting illuminating engineers in active practise. Nevertheless, the total amount of work which these engineers have been able to take care of has necessarily been small as compared with the free consulting engineering work furnished by the various manufacturers and central stations. Outside of the work done by the National Bureau of Standards, and in a few instances by various colleges, practically all the research work has been done by the manufacturing and central station interests.

Changing commercial conditions make it doubtful whether the manufacturing interests can take as active a lead in the future as in the past in the way of financing pioneer research work and high grade illuminating engineering work. Probably one of the most important and vital questions with which the Illuminating Engineering Society is confronted is that as to how illuminating engineering may receive adequate support from society in order to fulfill its proper field of usefulness to a reasonably adequate degree.

If this, then, correctly portrays our relation to society as a whole, we can well ask ourselves just what part this Society has played in the work already done. The Society has been the center around which all those who have done so much for the cause have duly revolved. The Society has been the clearing house for information and for the exchange of ideas, and were it not for its influence much of the good work might not have been accomplished. Contrast for example, the progress in good lighting and good illumination here with that of Europe. The good installation here is a commonplace; there a rarity. Exposed lamps here are rapidly leaving us; there they are the almost universal practise. Yet Europe is perhaps ahead of us in the use of modern light sources, the tungsten filament lamp, the mantle burner, the flaming arc, the high pressure gas arc, etc., but far behind in the good use of these sources. Can we not, therefore, instead of being discouraged over the smallness of results here

accomplished, feel that real progress has been made in this country in improving lighting conditions and that our Society has been a large factor in such progress?

Nevertheless we can ill afford at this time to rest content with what has already been accomplished. It is true that much has been done, but far more lies ahead of us. This Society must grow in usefulness to society at large, educational work on still broader lines must be undertaken and, by a united front presented by its members, further the progress of good illumination.

The Society needs new blood not only in its membership at large but also in its different governing bodies, for by the infusion of new blood is growth and progress assured.

Summing up, then, is it too much to say that this Society has and is fulfilling its true functions to society at large? It has done much to justify its existence, and, let us hope, will do much more in the future.

REPORT OF THE COMMITTEE ON PROGRESS.*

To the Illuminating Engineering Society:

The past year has been one of gradual and rather satisfactory progress in the science and art of illumination. No radical novelties in apparatus have forced their way to the front nor has there been any startling innovation in methods, but it is gratifying to note that more attention than ever before has been paid to the proper installation of lamps and the public has awakened to a fuller realization of the necessity of scientific methods in illumination.

PROGRESS IN GAS LIGHTING.

The most conspicuous advance in the material of gas lighting during the past year has been the extensive introduction of the artificial silk mantle. This material has shown itself capable of longer life and more uniform efficiency than anything yet tried as a material for mantles. A few inverted mantles of this type have been in use for some little time past. This year at last they have been pushed into extensive use and the upright mantles of artificial silk, previously not available in this country, have now been placed upon the market. The inverted mantle has been of late rapidly replacing the older upright mantle on account of its better distribution for most purposes and its better qualities in other respects. This year, however, the increase of interest in indirect illumination has again brought the upright mantle to the front as having a more favorable distribution for indirect lighting than the inverted mantle.

The use of high pressure lighting has increased conspicuously abroad, but as yet few and small permanent installations have been made in this country. The interest in the subject has been awakened, however, and the number of experimental installations has been considerably increased. Appliances of high pressure lighting have been materially improved so that there is good reason for paying more attention to this particular phase of gas lighting.

Among comparatively new uses of gas lighting, due to the availability of better and more powerful burners, can be men-

* A report read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

tioned the use of incandescent gas lamps by photographers, a comparatively recent innovation which has met with considerable success.

The general efficiency of the mantle burners in commercial use has been the subject of improvement and what is of greater interest to the public the manufacturers have met the demand for a wider range of burner sizes; so that there are now on the market burners, of both the inverted and the upright types, of many different powers, consuming from as little as 1 cubic foot of gas per hour up to 7 cubic feet.

It should be noted that improvement in gas fixtures during the past year has been somewhat noticeable, and particularly to be commended is the adoption of a standard specification calling for gas fixtures of better and more uniform quality. Such a specification is now in the course of preparation by representatives of gas companies and fixture manufacturers; it is expected that it will be generally adopted and produce a salutary effect on the quality of these installations.

ELECTRIC INCANDESCENT LAMPS AND LIGHTING.

The most important change of the past year in electric incandescent lighting has been the very widespread adoption of the drawn wire tungsten filament. Tungsten wire can now be drawn to a much smaller diameter than has previously been available; so that commercial tungsten lamps of as low as 10 watts have been produced, which can operate successfully on a 110-volt circuit. The 15 or 16-watt size, however, is the smallest tungsten lamp in any considerable use as yet. The smaller tungsten units are already in growing use abroad and bid fair to become an important factor in certain classes of lighting. The larger tungsten lamps up to 500 watts have within the last year awakened a considerably increased demand in competition with both gas and electric arcs. On the Continent tungsten lamps up to even 1,000 watts are coming into commercial use, but the largest of these sizes are still unusual.

The tungsten lamp as now used in this country remains at the same nominal efficiency as heretofore, but it must be noted that on the Continent 8/10 watt per candle is a specific consumption now very frequently quoted. This is based on the Hefner unit

and is therefore nearly 9/10 watt per candle when based on the international candle. At this figure an economical life of 500 hours or more has been repeatedly claimed. It would naturally be expected, therefore, that the lamps of manufacturers in this country may presently be rated at a higher efficiency than now, since there is no reason to suppose that the American product is in any way inferior to foreign lamps; but whether the necessary sacrifice of life would be desirable and advantageous may be open to grave doubt.

We are glad to be able to report that there is some chance of a reduction in the size of the bulbs of tungsten lamps, possibly at slightly increased trouble from blackening, but in view of possible better performance of the filament still leaving a residual advantage to the user.

The metallized filament carbon lamp has found its place for usefulness in the rapid replacement of ordinary carbon lamps for nearly all purposes. It is now available in all the shapes and sizes once familiar in the latter with equally good life and materially higher efficiency.

ARC LAMPS.

In this country the chief direction of advance in arc lamps has been toward the production of long burning flame lamps which have been adopted on a considerable scale in Chicago and at some other points. A fairly economical lamp of this type with an electrode life of 100 hours or more has been produced by several manufacturers and gives good promise of usefulness where units of high power are necessary. There is, of course, danger that attempts to increase the electrode life may entail serious loss in efficiency, but the present indications are that the improvement in the quality of the electrodes has in a considerable measure met this difficulty. The tendency is to use electrodes mineralized practically throughout, instead of simply in a core of modest dimensions carrying enough light-giving material to compensate in part for the longer time of burning per inch of electrode. The same tendency is active abroad and goes far to eliminate serious competition from the larger tungsten lamps by reducing the cost of operation of the arc lamps.

A three-phase lamp with three converging carbons has been

introduced abroad; it furnishes a very powerful light of remarkably low specific consumption and is adaptable for circuits of frequency as low as 25 cycles per second. In this country the principal novelty is the so-called "Boulevard" type of magnetite arc lamp which furnishes for spectacular illumination a unit of great power and efficiency extremely well suited to decorative purposes. This lamp is now used in a number of cities with admirable results.

The titanium carbide arc in an improved form has been introduced for use on alternating current circuits, and gives new promise of general usefulness.

Finally, intensified carbon arc lamps, which have been pushed to a point of high efficiency, have been steadily coming into increasing use,—well merited on account of their great regularity in performance and the admirable quality of their light where color discrimination is necessary. They are tending rapidly to replace the earlier forms of enclosed arc lamps which are now happily becoming obsolescent.

NEW TYPES OF ILLUMINANT.

The production of an artificial light capable of fully replacing daylight for color matching purposes has been a subject conspicuously to the fore during the past year. One type of intensified arc with a carefully adjusted glass screen of a highly ingenious character has come into use with good results. Two similar forms based on tungsten lamps with colored screens have also appeared. All three seem to produce pretty satisfactory results at, of course, a very much reduced efficiency. The use of the Moore carbon dioxid tube for the same purpose has increased. In this category might also be placed the mercury-vapor lamp with the rhodamine reflector. No device for obtaining daylight values of illumination sufficient to meet all the requirements of color discrimination has as yet been entirely satisfactory, all of those yet devised being open to criticism on theoretical considerations, though all are undoubtedly capable of great usefulness in meeting the trying conditions of this problem. It is fair to say that they do not vary among themselves more than the different conceptions of "white light" vary. It would be exceedingly interesting to see what could be done with

mantle gas burners properly screened in meeting this requirement. A daylight unit of this character is now being developed with promising results.

The most interesting of new illuminants from the theoretical standpoint is undoubtedly the neon vacuum tube lamp, developed in France, to which brief reference was made in the report of the committee on progress last year. Further details of its performance are now available. The rare gas neon, which forms a minor constituent of the atmosphere, can now be obtained in commercial quantities as a by-product of the preparation of liquid oxygen from air. The Paris works engaged in this industry even now can produce enough neon daily to fill 1,000 tubes of 1,000 candle-power each if so many should be required. The ordinary tubes are of about 6 meters in length and give about 900 spherical candle-power. The power factor is about 0.8 and its specific consumption is 0.72 watt per mean spherical candle-power at the terminals or about 0.9 watt including transformer and inductive losses. The color of the light is extraordinary, being a beautiful orange, entirely lacking blue rays, just as the ordinary mercury-vapor arc lacks red rays. No progress has yet been made toward the introduction of this interesting light into this country.

Finally, the quartz mercury arc lamps have made large progress within the past year. These lamps are not lacking in red rays as is the ordinary form of mercury-vapor arc, but are still subnormal in the red. It would be extremely interesting to know the result of operating them with the rhodamine reflector for a white light.

RESULTS OF TECHNICAL RESEARCH.

A considerable amount of work along physiological lines has been done during the past year both here and abroad. One of the results has been the suppression of the ultra-violet bugaboo by making it clear that under the condition of practical illumination, natural or artificial, there is substantially nothing to be feared from ultra-violet radiation, in which the light of the sky and that of several important commercial illuminants is somewhat rich.

Another line of investigation directed toward the value of

diffusion in illumination has furnished added evidence of its importance, not only in lowering the intrinsic brilliancy of all feasible sources, but also in reducing the reflected glare that is sometimes so serious an obstacle to vision.

Still another important addition to our knowledge lies in some of the photometric researches of the past year. Several of these have been directed toward the solution of some of the problems of heterochromatic photometry with the general result of strengthening the position of the flicker photometer for such purposes, and incidentally of showing the limitations of the more ordinary photometric methods and the devices by which they can be successfully applied to heterochromatic problems of the character usually arising in commercial photometry.

Important studies have also been made of the solution of photometric difficulties by methods eliminating the idiosyncracies of the eye through the use of selenium or other light sensitive cells. It has been shown, for instance, that for the selenium cell Talbot's law holds; and that within the bright part of the spectrum one can depend on a definite relation between the constants of the cell and the illumination, provided the latter be within determined limits. Curiously enough it is found that the constants of the cell vary so as to produce a species of Purkinje phenomena, the maximum sensitiveness lying in the yellow green at very low illuminations and in the red at very high illuminations.

There has also been a most ingenious attempt at producing a primary standard of light from incandescent platinum at the hands of two English investigators. A strip of platinum is electrically heated and held at a determinate temperature by the effect of the physical radiation filtered out through a water cell and a black fluorspar screen on a thermopile which indicates the radiant energy. The device was found to be good for a constancy within plus or minus ½ per cent., but whether it will prove any more workable in practise than various forms of the Violle standard remains to be seen.

NEW AUXILIARIES AND SOURCES OF BUSINESS.

The line of reflectors of various sorts available for the illuminating engineer has been largely increased during the past year.

The most notable change has been in the direction of indirect and semi-indirect lighting; the latter particularly has found numerous applications and the line of suitable glassware has been largely increased so that at the present time it is possible to obtain both indirect and semi-indirect lighting fixtures which are not only efficient but even decorative. As regards other shades and reflectors the principal changes have been in the direction of the improvement of metallic reflectors and their greater adaptation to meeting the requirements of the art of illumination, and in the production of well designed glassware of an ornamental character. The stigma placed upon the illuminating engineer that he has persisted in recommending hideous shades and reflectors bids fair to be permanently removed.

As regards increasing opportunities for use of light there has been a tremendous growth of so-called "great white way" lighting, generally carried out as the result of the private enterprise of boards of trade or groups of merchants. Some of it is admirable from the standpoint of illumination; all of it ought to be. Unquestionably, its effect will be greatly to increase the amount of street lighting whether it is permanently done at private expense or not. Illuminating engineers should use their best efforts when dealing with this class of work to make it so good from the standpoint of efficiency and artistic effect as to make it a permanent and growing branch of outside illumination.

In closing, it seems worth while in this connection to call attention to the efforts made last Fourth of July to introduce spectacular and sensational electric lighting as a substitute for the customary fireworks. Those who are laboring to secure a "safe and sane" Fourth can hardly do better than to direct their energies toward satisfying patriotic young America with flamboyant and gorgeous civic fetes rather than by spectacular conflagrations. How thoroughly this substitution can be effected is uncertain, but if carried out it certainly would decrease the activity of the firemen and the hospitals.

Respectfully submitted,

George S. Barrows,
Percy W. Cobb,
Louis Bell, Chairman.

DISCUSSION.

Dr. H. E. Ives: I know that it is an extremely thankless job to write a report of any sort, and it is therefore with some hesitation that I rise to make criticism. There are, however, several places in this report in which general statements are made which I believe should be made explicit. There are some matters, which I do not find mentioned in it at all, which I think are more important than those which have been included.

On the fourth page: I am interested to know what is meant by the statement that all color matching devices thus far produced are open to criticism. I know of no definite statement which has been made in the technical press and I would like to know where and by whom the work has been done to justify such a reference.

I read in the report, on the sixth page, a reference to the selenium cell which seems to indicate that this may develop into a very useful thing. I am pretty familiar with the recent work on this cell and draw a very different conclusion from that given here. The fact is that selenium is so complicated in its action as to be almost hopeless for photometric purposes. On the other hand a great deal has been done with the photoelectric cell, and I am sorry not to find a mention of this in the report.

On the same page also, I find a report of an attempt to produce a primary standard of light by radiation measurements of temperature. My recollection of this work is that the investigators exhausted a grant of money made for the purpose and then reported rather dubiously on its practicability. There have been some very important suggestions pointing to truly scientific radiation standards during the past few years and I am sorry not to see them embodied in the report.

Mr. G. H. Stickney: I notice a reference to the increased efficiency of the tungsten filament lamp in regard to the European practise and the statement is made that we are likely to go further in this direction in this country. In this connection, you will notice that with the increase in efficiency there is brought about a considerable shortening of the life. This may or may not be an advantageous step for everybody concerned. In regard

to the question of the policy of adopting efficiencies. I would like to say that the General Electric Company makes it a practise to co-operate with the central station and other lamp users and is setting those efficiencies which will serve best the interests of all concerned.

Dr. C. H. Sharp: Referring once again to the neon light, I may be able to add a few details of interest to the members. I was fortunate last summer in being able to call upon the gentleman who has developed the neon tube light. I saw him in his laboratory, which is in connection with his extensive works for the liquifaction of air in the suburbs of Paris. The liquid air establishment itself is well worth a visit. They turn out liquid air in tremendous quantities, and then, by distillation, get quantities of liquid oxygen. Neon is a by-product; it exists in the air only in excessively minute quantities, but where the air is liquified by the wholesale, the amount of neon obtained is considerable. The tubes are six meters in length. They are operated from a transformer at about 1,000 volts, I believe. As is the case with the Moore tube, there is a large fall of potential (200 volts) at each terminal. The fall through the gas in the tube is much smaller, about 100 volts per meter; consequently, the longer the tube, the more efficient it is. The standard tubes have a diameter of 45 mm. They are prepared in six meter lengths and shipped out ready for use; that is to say, they are not exhausted on the spot, as is the case with the Moore tube. There is no arrangement for supplying additional gases, but the amount of gas which appears during operation is reduced to a minimum by the use of very large electrodes in the tube. The exhaustion is necessarily carried out in the factory. The neon must exist in extremely pure form; the presence of very slight traces of other gases such as nitrogen has the effect of decreasing the efficiency very greatly. The exhaustion of the tube is effected by Dewar's process of using liquid air and charcoal by which diluting gases are condensed out, and this insures a very high degree of purity. The life is about one thousand hours and the efficiency, as I remember it, is as given in the report, and I presume that this is correct.

The light emitted from the neon tube is orange in color; in

fact, it is a very red orange, and in comparison with daylight it looks extremely red. After working under it for a while, however, the eye adapts itself to that color and the color of the light is not very objectionable.

I may say that we had the promise of a paper by M. Claude and also of one of the tubes for exhibition. There was also the possibility of his being here in person, but he has been obliged to disappoint us; otherwise we might have had the very great pleasure of seeing this new form of illumination in operation.

Mr. C. W. Deshler: A reference is made on the second and third pages of the report to the efficiency of tungsten filament lamps. It may be interesting to know that within the past two years very marked improvements have been made both as regards 80 per cent. life and efficiency especially in the 250, 400 and 500 watt types, viz.:

Year	Commercial efficiency	Life to 80 per cent. of initial c-p. at 1 w. p. c.	
1910-11	1.13	250	Ungettered
1911-12	1.13	550	"Getter" 1
1912-	1.00	1000	"Getter" 2

Mr. D. McFarlan Moore: I heartily agree with this report, in the statement that the most interesting of the new illuminants, is the neon light; but perhaps the last statement is a little misleading in that it is said that no progress has been made in the introduction of this light into this country. About twenty years ago, I commenced trying out, in vacuum tubes the known gases, and came to the conclusion that the ideal gas or gases was yet to be discovered.

But by using a number of well known gases, particularly nitrogen and carbon dioxid in combination with an automatic valve to resupply the vacuum tube with gas at short intervals, there resulted what is known as the "Moore Light." When later neon was discovered, I immediately thought of its application to the various forms of my vacuum tubes and made every effort to obtain information regarding its production and qualities. A few years later, 114-foot lengths of Moore light tubes were being installed on the front of the Grand Palais in Paris, and the request of a liquid air manufacturer to try neon in the Moore tubes was granted. The results of this first experiment were encouraging. Since then various experiments have been carried

on along this line. During the past few months the entire Moore light interests have been taken over by the General Electric Company. and considerable development work is in progress. Sir William Ramsay, the discoverer of neon, called upon me last week and kindly presented me with a quart of neon.

It is probable, that this gas will have a large commercial application in Moore light tubes.

I believe monochromatic light will be produced by the vacuum tube for one-fiftieth of the cost of its production by the best electric lighting systems of to-day, which are headed by the long tube Moore light system using nitrogen, and neon has an efficiency about 400 per cent. better than nitrogen.

The paragraph under the heading "New Illuminants" is also interesting. It refers to three possible methods of producing a color matching light. Two of these methods consist of proposed means of attempting to correct the spectrums of either the arc or incandescent lamp, and have fields of usefulness where approximately correct color values are desired; but the white Moore light, which is due to the passage of an electric current through carbon dioxid, *naturally,* has perfect color values and needs no correction whatsoever. It has repeatedly been proven to be nearer the theoretical standard white light than the variations of the best qualities of average daylight. Its light is so evenly distributed throughout its spectrum, that it is impossible to detect the fact that its spectrum is not perfectly continuous, by any color discriminations, concerning the most delicate shades of any hue.

Dr. K. G. Frank: The tendency in Europe at the present time is not to use flaming arc lamps for less than 8 amperes, because the steadiness of light and the efficiency of the lamp decreases considerably in using currents of about 6 amperes or less.

Dr. Louis Bell (Communicated): As chairman of the committee on progress, I feel it incumbent on me to offer a word of explanation concerning some of the friendly criticisms passed on the report.

As regards the neon tube, I would certainly be the last to detract anything from the credit due Mr. Moore in the matter of gaseous illuminants. He deserves a place in the front rank

of the procession, but his own statement shows that the neon supply necessary for investigations only reached him after the report was in print, so we are quite justified in intimating that we had no progress to report in this country along that line. I trust that next year there may be a great deal of progress to report regarding Mr. Moore's own work.

Had space permitted, the committee would have been very glad to go fully into many matters of technical interest, as for example, the photo cell and its uses. That it is capable of great usefulness in certain photometric researches, the marvelous results reached by Prof. Stebbins in stellar photometry plainly show, and it is certainly a matter of regret that it has not yet been found more applicable to commoner problems.

There is much to be said for the proposal that the report of progress should be made a complete record of everything that has been done during the year along the line in which we are all interested. I do not think, however, that the advocates of this course fully realize what carrying out such a project would mean. It would require reading, abstracting, classifying and indexing probably not less than one thousand articles per year, appearing in three or four languages, and a score of publications. When published it would of itself fill a large number of our TRANSACTIONS. At some future time it would be an admirable work for the Society to undertake, but I do not feel that it falls within the scope of ordinary committee work.

SYMPOSIUM ON HIGH PRESSURE GAS LIGHTING.*

PART I.—HIGH PRESSURE GAS LIGHTING IN GREAT BRITAIN.

BY F. W. GOODENOUGH.

I have been honored by a request to write a communication descriptive of the progress made with lighting by gas under increased pressure in Great Britain (and more particularly in the City and County of London, with which I am the best acquainted); and I will therefore endeavor to give a brief account of the development and present position of high-pressure gas lighting in this country.

Before doing so, I might perhaps with advantage explain—in as non-technical language as possible—the main objects in view in working with gas at a higher pressure than is normally supplied in the mains.

With the ordinary pressure available, say 2 to 4 inches (5.08 to 10.16 cm.) water-gauge, it has not so far proved practicable, in an incandescent burner, to obtain the aeration of the mixture necessary to give the maximum flame temperature, and also to impart sufficient energy to the mixture to overcome the resistance of the burner and mantle at an adequate velocity.

Velocity is not only necessary to get the maximum incandescence to the mantle, but also to prevent the lighting back of the mixture.

The importance of obtaining the highest flame temperature possible will be appreciated when it is realized that, according to the best authorities, the light emitted by a mantle increases as the twelfth power of the absolute temperature. It has been stated to be as high as the fourteenth power; but even if the rate of increase was considerably less than the lower of these two estimates, it will be seen that every degree of temperature that can by any reasonable and economical means be added to the flame will pay handsomely.

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

So far as I can discover, the earliest form of high-pressure burner and apparatus was devised by a Belgium gas engineer, M. Greyson de Schott, of Namur, about the year 1896. This found its way into England in the following year.

The burner consisted of an upright burner giving about 300 candle-power and the compressor was a somewhat crude apparatus driven by water-pressure, with a large gas bag on the inlet and outlet of the pump. The apparatus was not automatic in its action, but had to be regulated by hand, the outlet pressure being kept steady at 8 inches (20.32 cm.) water gauge by a governor on the outlet of the high-pressure gas bag, which latter was enclosed in a net.

While the burner and apparatus were very crude, they showed the possibilities of increased pressure, as not only was the efficiency of the ordinary burner about doubled, but the possibility of larger units of light than had hitherto been available was demonstrated.

In the following year a considerable improvement was effected in the compressing apparatus with the introduction by the James Keith & Blackman Company, of London, of an improved form of water compressor from which most of the objectionable features of Greyson's apparatus were removed. In this apparatus the pressure, which was still 8 inches (20.32 cm.) water-gauge, was obtained by substituting for the solid piston a double acting water-sealed bell actuated directly by a water motor, the delivery from the pump being passed into a small holder weighted to the desired pressure. The holder was arranged to control the water supply to the motor so that the latter was quite automatic in its operation, starting and stopping with the turning on or off of the gas at the burner.

For several years this and similar types of apparatus were chiefly used, although certain other more or less successful attempts were made to produce pressure by other means, such as by water injectors, pumps driven by hot-air motors, or by electric motors, etc.

Mention must especially be made of the work in this direction of the late Mr. William Sugg and his firm, by whom were carried out successfully a number of important installations includ-

ing one at the Marylebone Station of the Great Central Railway, and a particularly striking one on the outer railings of Buckingham Palace.

Among other experiments in the field of increased pressure gas lighting, an interesting and ingenious arrangement may be mentioned, viz., the Scott-Snell self-intensifying lamp in which the waste heat from the burner was employed to operate a form of hot air motor, which in turn raised the pressure of the gas used in the burner by means of a pump. Later on it was found more satisfactory to pump air instead of gas and inject this into the burner in order to give the necessary aeration and velocity to the mixture. Unfortunately, however, the delicacy of this apparatus necessitated too much attention for practical working.

In the meantime, various other attempts were made to increase the aeration of the mixture by other means than by increasing the gas pressure, the chief of these being known as the "Lucas" self-intensifying lamp, in which a long chimney is utilized to assist the injector by drawing an increased quantity of air through the Bunsen tube. Many variations have been made on this principle; but the limitations due to the great length of chimney, and to other difficulties which need not be entered into here, have prevented a general adoption; and while the results were an advance on those obtained from ordinary burners, they could not be compared with those eventually obtained by the high-pressure system.

In the meantime considerable improvements in the latter system were made, in regard to the details of burners and lanterns, fittings, etc.; but, as in all these systems, the vertical burner was used; and while the practical working was much improved, very little advance in efficiency was made on the results achieved by the original Greyson burner. In some cases higher pressures were used, but the benefit of such higher pressure was doubtful, being indeed to a large extent necessitated by the crudeness of some of the burners employed.

The introduction of the inverted burner for low pressure did not at first appear to give any scope for the use of high pressure, as the principle upon which the ordinary low-pressure inverted

burner works did not necessitate such a highly aerated mixture (in fact, the burner would not work with it) as was used with the upright high-pressure burner. But after some little time it was found that if instead of causing the flame merely to lick the inside of the mantle while allowing the products of combustion to pass out between the ring and the burner tube, the flame was forced through the meshes of the mantle by means of high pressure, and the products of combustion were made to pass away from the outside of the mantle; a considerable improvement was thus effected over the results obtained at low pressure. To do this, it was of course necessary to close the space between the ring and the burner nozzle.

In the year 1907 a great impetus was given to high-pressure gas lighting by the introduction of a new type of inverted burner by the Keith & Blackman Company, in which a large proportion of the waste heat from the burner was utilized to preheat to a considerable extent the mixture of gas and air before the point of ignition. Owing to the greatly increased resistance caused by this burner, due to several reasons, into which I need not enter here, it was found necessary to raise the pressure used very considerably, namely, to about 54 inches (1.371 m.) water-gauge, or say 2 pounds per square inch (6.45 sq. cm.).

Under certain circumstances, it has been found that even higher pressures are necessary. In fact, the whole tendency seems to be to increase the pressure, and, so far as can be at present foreseen, any further advance in efficiency must be accompanied by additional increase of pressure.

The immediate result of this new system was just to double the efficiency of the light; and with a gas of average quality, an illuminating value of about 60 candles per cubic foot was obtained. Not only was the efficiency raised to this extent, but the size of the mantle required for a given unit of light was very much reduced. This reduction in the size of mantle in relation to the candle-power evolved, made it possible to obtain practically very much larger units of light than had hitherto been possible; and as its advent was practically coincident with the widespread adoption of the flame arc lamp, a general tendency towards the use of very large units of light was to be

observed as a consequence—one of doubtful value from the illuminating engineer's point of view.

So far as I can gather, the average quality of gas in the United States is considerably higher in candle-power and heating value than in Great Britain; so that there should be no difficulty with such gas in obtaining considerably higher results than 60 candle-power per cubic foot. Mr. C. A. Luther of the People's Gas Light and Coke Company, Chicago, has, in fact, recorded as high an illuminating value as 80 candles per cubic foot with one of the Keith lamps.

The possibilities of this system were demonstrated for the first time to the public in a very striking manner by the lighting with Keith lamps of a large portion of the grounds of the Franco-British Exhibition, and of the grounds of the Scottish National Exhibition held in Edinburgh, both in the summer of 1908.

The necessity for a higher pressure for such types of burners made it compulsory to depart from the automatic water-driven type of compressor, and its contemporaries, and to adopt a more positive type of compressor driven by power. The most usual form is of the rotary blower type, somewhat on the principle of gas exhausters, but fitted with suitable arrangements for regulating the pressure so as to keep it constant, independent of the number of burners which are in use, or any variations in the speed of the driving power.

The introduction of the inverted high-pressure burner has also revolutionized the type of lantern used, more especially for outdoor purposes, and has led to the universal adoption of the so-called "arc" type of lamp with suspended globe. Even in the days of the lower powered high-pressure upright burner, it was found that the square or hexagonal lantern, generally fitted with flat panes of glass, was not the most suitable type, as great trouble was experienced with the breakage of glass due to the considerable amount of radiant heat. It was also found that while formerly it had been the best practise to construct the tops and chimneys of outdoor lanterns of copper, this material very rapidly oxidized and flaked away in high-pressure lamps owing to the high temperatures of the products of combustion. For

outdoor high-pressure lamps it was found that a lamp casing and chimney made of enamelled steel, when properly designed, had a much longer life than the copper lantern; and with the introduction of the inverted burner with still higher pressures, and much higher lighting units, the difference was even more marked, with the consequence that the present day the use of copper lanterns has almost entirely given way to enamelled steel casings for high-pressure outdoor lighting.

With the new or "arc" type of lantern, globes made of ordinary glass were at first used and gave good service as compared with the flat-pane type, but on the introduction of the larger units of lighting, and the demand for lamps of smaller dimensions, it became necessary to substitute globes made of the best fireproof glass.

PUBLIC LIGHTING.

On the first introduction of the high-pressure system, most of the installations carried out were for private consumers, generally for the lighting of factories, and a very great number of plants have been installed for this purpose; but its great value as an illuminant for street lighting purposes soon became apparent, and considerable use has been made of it for public lighting both in London and in the provinces.

The beginnings in this direction were somewhat modest, and mainly consisted of isolated units on island street "refugees," generally over public conveniences—mainly for the reason that a position had to be found for the use of the water-driven compressor usually employed. This gradually extended to the lighting of important junctions of streets, such as at Ludgate Circus, outside the Mansion House, in front of the Royal Exchange, etc., and to Blackfriars, London and Vauxhall Bridges across the Thames.

These demonstrations so conclusively proved the value of the high-pressure system for street lighting, that in the City of London proper a considerable extension was made in the laying down of mains which were fed from a central point where the compressor could be fixed. One of the most important of these was in the neighborhood of Billingsgate Fish Market, and the streets around the Monument on the city side of London Bridge.

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About the same time a very important installation was completed in Queen Victoria Street, from the Bank to Blackfriars. In this particular installation, advantage was taken of the fact that a subway runs the entire length of this street, and that a high-pressure main for feeding district holders in London from the gas works at Beckton already existed in this subway. As, however, the pressure in this main fluctuated, it was necessary to control each lamp service by means of special governors reducing the pressure to a constant 8 inch (20.32 cm.) water-gauge, the governors being fixed in the base of the lamp columns.

Shortly after this, the opening of the new thoroughfares of Kingsway and Aldwych, gave an opportunity for the introduction of high-pressure gas lighting, advantage being taken of the subway which was constructed to lay special high pressure mains. Lanterns fitted with clusters of two and three light upright burners were fixed on tall steel columns, and a pressure of about 40 inches (1.016 m.) was used on the millenium principle which had been largely adopted in Birmingham. The compressors and engines were fixed in an adjacent vault.

Another important installation of lamps with upright burners at 16 inches (0.406 m.) pressure was supplied by Messrs. William Sugg & Co., for the lighting of Whitehall and Parliament Street in 1905.

At the end of the year 1908, owing to the impetus given by the successful lighting of the Franco-British Exhibition, the city authorities decided to light Fleet Street by means of the newer system of high-pressure inverted burners, and these were duly installed and lighted on Christmas Eve. In order to reduce the obstruction previously caused by lamp-posts the lanterns were suspended from large brackets fixed on buildings. A large compressing plant was put down in an adjacent street, with a view to extensions of street lighting, and also with a view to supplying private consumers with high-pressure gas for the lighting of factories, printing houses, etc., on the line of route. The installation was shortly afterwards extended for the lighting of Ludgate Circus, New Bridge Street and the approaches of Blackfriars Bridge. Subsequently a large number of important printing houses taking advantage of this main installed

the high-pressure system both for lighting and for furnace heating. Among others may be mentioned the premises of Messrs. Cassell & Co., Ltd., and of Messrs. Bradbury Agnew & Co., the well-known printers of the world-renowned *Punch*.

The success of these installations,—particularly that in Fleet Street,—encouraged other local authorities to investigate the claims of high-pressure gas, and, in 1910, tenders were invited by the Corporation of the City of Westminster, for the relighting of some of the most important streets in their area, comprising: Regents Street, Pall Mall, St. James Street, Whitehall, Victoria Street, Westminster, Piccadilly, Shaftesbury Avenue, and Charing Cross Road.

The terms of this contract (based upon the contracts for the lighting of Kingsway, Aldwych and Whitehall) was somewhat novel, as a minimum candle-power had to be guaranteed by the successful tenderers against a penalty. This form of contract is now known as the "Westminster specification," for which Mr. J. W. Bradley, the city engineer, was primarily responsible.

The Gas Light and Coke Company was successful in securing the contract for this work for a period of five years.

The result has fully justified the action of the Westminster City Council, and their engineer, as the streets above mentioned now comprise, without question, the finest lighted area to be found anywhere. Reports are published from time to time giving the results of the regular testing of these lights by the Council, from which it is seen that the average result obtained is well above the guaranteed minimum in all cases.

Other important installations have since been put down in Birmingham, Glasgow, Cardiff, Manchester, Newcastle and in other leading provincial cities.

Recently a portion of New Oxford Street and High Holborn has been lighted by high-pressure gas, and it has also been decided to relight some of the principal thoroughfares in the City of London proper by this means.

In the latter scheme, all the thoroughfares originally lighted by high-pressure gas on the earlier systems, with some additions will be converted to the newer system of inverted burners, but with very much higher lighting units. In many cases, instead of

the lamps being fitted to columns or brackets, they will be suspended from the middle of the street by means of wire ropes, and arranged in such a way that they can be drawn to the side of the street and lowered within the pavement line for maintenance, the lighting and extinguishing being controlled from boxes on the wall.

In the meantime, other countries on the Continent of Europe have not been slow to recognize high-pressure gas lighting as an efficient illuminant for street lighting where large units of light are desired. The most notable instance is that of the City of Berlin, in which many miles of the principal streets are now lighted by means of high-pressure gas.

Moreover, it has recently been decided to relight the main streets of the City of Paris by high-pressure gas.

For all this, I consider it necessary to say that, while fully recognizing the value of high-pressure systems for securing maximum efficiency where largs units of light are specially desired, I think the craze for such large units has been carried too far; and to point out that recent advances in the efficiency of low—*i. e.*, ordinary—pressure inverted burner lamps have made it necessary always to draw up a careful balance sheet of the total cost per candle-power required, taking all factors of initial and running costs into account, before deciding whether to adopt high or low-pressure systems of lighting. The dearer the price of gas the stronger the case for high-pressure, which economizes in gas consumption, while being more expensive in first cost and maintenance.

Obviously, no one would choose a high-pressure in preference to an ordinary pressure system unless the former showed a substantial saving per candle-power developed.

PARADE AND SCALE LIGHTING SYSTEMS.

Under this heading I propose to give a few facts about a system of high-pressure gas distribution which has made great strides within the past few years. This is known as a "scale" or inclusive charge system, under which the consumer pays an inclusive price per lamp per annum according to "scale," the price varying with the desired hours of lighting. It was originated by some of the gas companies in London making arrange-

ments with a limited number of shop-keepers in a block of buildings, sometimes known as a parade (hence the name) to put down a small compressing plant in an adjacent basement, and run a supply along the building fronts to feed high-pressure lamps outside the shop windows.

Owing to the fact that a constant pressure can be relied upon, the consumption of such lamps per hour is a known quantity; and as the control of each of these plants, and the lighting and extinguishing of the lamps, is in the hands of the gas company, it was a simple matter to arrange a fixed price per annum to cover the cost of working, the hire of lamps, maintenance, gas supplied, etc.

In order to meet the varying requirements of different tradesmen, a schedule of rates is arranged according to the hours of light required. While they are all lighted automatically by the starting of the compressor at the same hour, they are extinguished by the companies' men at different times, according to requirements. In this system there is no necessity to meter the gas and it does not enter the consumers' premises.

The immediate success of these small installations led to their being rapidly multiplied, so that in certain instances it was found more economical to couple them up by means of a main worked from some central point, thus doing away with the smaller compressing units.

Owing to the popularity of this arrangement, many of the gas companies in London have now put down long runs of high-pressure mains for supplying lamps on this system. The mains are generally run under the pavement on each side of the street, so that the roadway has not to be disturbed to make a connection.

The Tottenham and Edmonton Gas Company, which was one of the first companies to go in for this system on an extensive scale, has now some twelve miles of mains entirely devoted to this purpose, and the South Metropolitan Gas Company has recently extended its system to fourteen miles.

At the present moment, in London and its vicinity, it is calculated that there are over 12,000 lamps, of an average candle-power of 1,000, now in use supplied by six gas companies, and

these are being constantly added to. The majority of these have been fitted up within the past two years.

In the Gas Light & Coke Company's area there are over 3,500 of these lamps supplied on this system.

In the case of the main by which they supply the Cities of Westminster and London, a constant pressure is kept up, and a supply is available, not only for scale lighting, but also for various factory and industrial purposes through the daytime. A very large installation on this main is Victoria Station of the London, Brighton & South Coast Railway, which is lighted throughout by high-pressure gas.

FACTORY LIGHTING.

It is only within the past two or three years that much progress has been made in public street lighting and the "scale" lighting before referred to, but high-pressure gas lighting secured a firm footing in factories and workshops almost from its first introduction, and it is chiefly in this field that the system has been developed in the past.

The existence of power on the spot or the presence of workmen who can look after the running of a plant are factors in favor of adopting the system in the case of such premises. The flexibility of the size of units is also an advantage, as it is possible to use efficiently from one cubic foot per unit up to say 75 feet and more, from the same supply; while in many cases the high-pressure gas can, at the same time, be advantageously used for industrial heating purposes. A notable instance of this dual purpose is seen in the case of laundries where the high-pressure gas is used for heating the gas irons and rollers of machines in place of the old air blast system, with a considerable economy (amounting in some extreme cases to as much as 50 per cent.), chiefly owing to the better control and regulation of the mixture.

Within the past few years there has been in Great Britain a marked advance in the use of town gas for all sorts of industrial heating and melting purposes, and this advance has been largely brought about by the convenience and efficiency of high-pressure gas for such purpose. In the City of Birmingham a large high-pressure main has been put down, distributing over a large area

gas at 15 pounds per square inch, chiefly for such purposes, its use for street lighting being merely a secondary consideration.

The laying down of such mains will have a very marked influence on the progress of the use of high-pressure gas for all purposes, as they do away with the inconvenience of individual compressors. There are still a few problems to be solved in the successful metering of such supplies, and while meters are manufactured for this purpose, they have not yet come into general use. The difficulty lies in the fact that under varying pressures the gas has a varying volume, and this has to be compensated for. I have little doubt that in a very short time this problem will be satisfactorily solved, as other difficulties have been overcome in the past.

I will conclude these very inadequate notes by repeating that, while illuminating engineers as well as the gas industry have much and may in future have still more for which to thank those who have devoted much time, money and ingenuity to the development of high-pressure gas lighting, and while it may be true that the future of gas lighting for trade purposes may lie in that direction, the battle is still in process between special or high and normal or low-pressure systems, and every case must be considered on its merits. The latest advances have been in favor of the normal pressure; but, where a large number of very large units of light are required, the high-pressure system is easily first.

PART II.—HIGH PRESSURE GAS LIGHTING IN GERMANY.

BY OSCAR KLATTE.

Remarkable development in high candle-power gas lighting, both by means of gas under high pressure (about two pounds) and by the use of gas at ordinary distribution pressures and air under high pressures (about half a pound), has taken place in Germany during the past ten years, so that in nearly all of the leading cities one or the other of these systems is in vogue.

These systems are used for lighting the principal thoroughfares and the squares or parks, and many ingenuous methods for lowering the lamps for trimming have been devised.

Many of the streets are lined with trees, so that to obtain the best illumination results, it has been necessary to hang the lamps over the center of the street. This has been accomplished both by the use of a pole with long projecting arm and by a wire suspension device, the wire being attached to the poles on opposite sides of the street.

Where the pole with the arm has been used, the arm is made with a double swing joint, so that lamp may be lowered to a convenient point for trimming. Where the wire suspension is used, a travelling block is installed, so that the suspension hook may be hauled to the side of the street and the lamp lowered so as not to interfere with traffic. Where this method of suspension is employed, the gas or air connection is made through a flexible tube.

The lamps used have one, three four or five mantles, and vary in candle-power from 500 to 4,000.

An indication of the growth of this form of lighting is found in the city of Berlin. Up to 1905, about 15 miles[1] of street were lighted with electric arc lamps, and from 1905 to 1911 one mile of electric lighting was added. In 1905, about 4 miles were lighted with high pressure gas, but during the period from 1905 to 1911, 32 miles of high pressure gas lighting were added, and a further extension of 42 miles is contemplated.

While the use of pressure gas lighting is more or less commonly seen in various parts of the world for street lighting, in Germany

[1] One mile = 1.609 km.

it is used, not only for lighting streets, but also for lighting freight stations, amusement parks and similar enclosed or semi-enclosed spaces where high candle-power units are suitable; and the use of this method of lighting with single mantle units and indirect fixtures is being developed for the illumination of drafting-rooms and schools.

Indications point to a greatly increased development of this method of lighting for all purposes.

PART III.—HIGH PRESSURE GAS LIGHTING IN AMERICA.

BY R. N. ZEEK.

High pressure gas lighting in America has not reached the same state of development that it has in either England or Germany. This, undoubtedly, has been due to the fact that pressure gas lighting has never been pushed in this country as a commercial possibility; however, with the number of installations now being operated successfully, there is every reason to suppose that this form of lighting will take its place among the more common ones.

I shall attempt to confine this paper to only a description of each of the six installations at my command; but a few words giving the reason for the advent and also the development of pressure gas lighting will not be amiss at this point.

It is a well known fact that increasing the pressure of the air or gas delivered to a lamp increases the efficiency at least 40 per cent. That is to say, if the candles per cubic foot of gas consumed for a low pressure lamp is 15, then the candles per cubic foot of gas consumed for this same lamp if supplied with pressure gas would amount to 21. It does not follow, however, that low pressure lamps can be installed on a high pressure system with satisfactory results. The products of combustion from such an installation would be entirely too hot and abundant to insure the positive operation of the appliance. Then again the air ports of a low pressure lamp are altogether too small to supply the requisite amount of air for higher consumptions. The above increase in efficiency is due to the fact that the mantles can be made much longer, thereby exposing a greater surface to the bunsen flame and requiring only a slight increase in consumption to obtain this long flame as well as the attaining of a higher temperature. This fact together with the increasing popularity of high pressure gas distribution indicates that it is only a question of time when lamps can be installed in any locality and connected to the high pressure mains through individual governors.

The installations which I propose to describe are in Philadel-

phia, Waterbury, Conn., Wilmington, Del., Washington, Des Moines and Chicago.

The installation in Philadelphia consists of seven two-arm ornamental posts equipped with fourteen two-mantle lamps, located on Broad and on Arch Streets, around the United Gas Improvement Company's building.

The ordinary pressure in a gas mantle supplied from the mains is about 1.5 ounces, but in the system under consideration this pressure is increased by a blower to two pounds.

The gas comes from a street main through a special service, passes through the meter, and then through an anti-fluctuator placed in the line to prevent any possible fluctuations from the compressor being noticed in the service. From the blower the gas goes to a storage tank through a relief valve so adjusted that, when the pressure is in excess of five pounds, the gas is by-passed through the relief valve and through the inlet to the governor. The storage tank in this case is a 100-gallon hot water boiler, and its great capacity prevents any fluctuation being communicated to the governor. From the storage tank the gas is conducted through a governor weighted to throw an outlet pressure of two and one-quarter pounds, thereby insuring two pounds at the lamp.

The blower or compressor is, in this case, directly connected to a specially wound motor, but there is no reason why the compressor could not be run by a belt connected to either an electric or water motor, or a gas engine. In some of the installations gas engines are used to drive the compressor, and are so located that they can be used for demonstration purposes.

A separate line of piping was run to supply the pilot lights of the lamps. This pilot is controlled from a point in the basement, and the compressing plant has a valve arranged with a lever which may be set in three positions, one entirely off, which is the position of the cock when the lamps are burning and the pilot gas is entirely off. The second position is with the valve about half way open, which is the position during the day or when the lamps are extinguished. The third is when the valve is entirely open, giving a long jet, or practically a flash pilot, and is used only for a short time when the lamps are being

lighted from the pilot, or when the pilot in turn is being lighted from the lamps.

The entire compressing plant is installed in duplicate as an emergency precaution.

A few figures on the illumination obtained from these lamps will be of interest here. The two lamps on each post are hung 16 ft. 6 in. (4.03 m.) above the pavement, while the posts are spaced 35 ft. 6 in. (10.82 m.) from center to center. Considering the plane of illumination 3 ft. (0.609 m.) above the pavement. the average illumination was 3.0 foot-candles. These readings were taken within a radius of 15 ft. (4.57 m.) from the base of the post, and strange to say, all of the readings were very uniform. This was undoubtedly due to the fact that directly below the mantle where the distance was the least, the smallest possible incandescent surface was exposed to the disk of the illuminometer.

The shape of the light distribution curve from the lamp bears out this argument. The shape of this curve indicates that the lamps are peculiarly well adapted to street lighting, since directly below the lamps the candle-power is 480 and at 65 deg. the candle-power is 920.

In Waterbury, Conn., the case is an entirely different one. Seven single mantle lamps are installed on as many posts at the approach to the railroad station. A high pressure main supplying an outlying district passes through this locality, when made the installation of high pressure lamps a very economical and easy one.

The pressure on the main line supplying these posts varies from ten to twenty pounds per square inch (6.45 sq. cm.) during a twenty-four hour day. This pressure is reduced by means of a small governor, 3.5 in. (8.89 cm.) in diameter, located on the line in the base of each post, to two pounds which is the pressure best adapted to this particular lamp.

The lamp is operated by means of a pilot light supplied through the main cock at the lamp, which cuts off the pilot during the lighting hours. The lamp cocks are operated by a lever with a light rod attached, extending down the post to within eight or

ten feet of the ground, for convenience in lighting and extinguishing.

The installation at Wilmington, Del., is similar to the one above described in operation in Philadelphia. There are four single mantle lamps installed on posts on the Market Street front of the gas company's building. The pressure is obtained by means of a compressing plant in the basement of the building and the lamps are operated and controlled in much the same way as in Philadelphia.

The installation in Washington, D. C., consists of six two-mantle lamps installed on three posts in front of the general offices and four single mantle lamps installed on two posts in front of the sales department offices. The pressure is obtained by a compressor located in the basement, and the operation of the lamps and pilots is similar to that described above in the case of Philadelphia.

Des Moines, Ia., has six single burner high pressure lamps installed on three ornamental curb posts. The pressure is obtained from a compressing plant in the cellar, operated by a 2.5 horse-power gas engine which serves the double purpose of being an exhibit for the sale of gas engines as well as furnishing the power for the compressor. The method of operating the lamps and pilots is identical with those previously described.

The installation in Chicago consists of 40 single mantle lamps installed on brackets between the columns of the Peoples Gas Light & Coke Company's building.

The lamps are operated on gas boosted to two pounds pressure and to secure the increase in pressure on these units there has been installed in the sub-basement a duplicate booster set, consisting of two four horse-power motors direct connected to two blowers. They are so connected as to eliminate the possibility of allowing the pressure to drop back to city pressure, inasmuch as the motors are connected to a specially constructed panel board arranged so that if one machine should stop from any cause whatever, the other machine is automatically thrown in and takes up the load.

The boosters will give a pressure of five pounds per sq. in. but the gas is not delivered to the lamps at this pressure. A

specially contsructed governing by-pass is used which by-passes the excessive amount of gas back through the booster again.

There are other systems on the market; one especially, where the air is delivered to the lamp under pressure—about 2 in. (5.08 cm.) of water—is extensively used; but of course in this case another pipe to each lamp is required.

In these cases the efficiency will be practically the same as with the pressure gas lamps.

Since high pressure gas lighting has passed the experimental stage, and for a number of years has been so successfully operated in America, there is every reason to suppose that in the near future this form of lighting will be as prominent as either low pressure gas or electricity is to-day.

DISCUSSION.

MR. W. J. SERRILL: The problem of running high pressure gas lamps, under the weather conditions existing in this country, seems to have been solved. We now have what may be called practicable high pressure gas lamps. We have just passed out of the experimental stage, and this accounts for the fact that so little has been done with high pressure lighting in this country.

I might say incidentally that a pressure of two pounds seems to have been adopted as the standard pressure for high pressure lamps.

Many gas companies in this country, until recently, have looked upon street lighting with gas as unprofitable business and have not actively pushed for it. I refer especially to the lighting of business sections. Now that they have practicable high pressure lamps, it seems to me that the gas companies should wake up.

MR. H. H. MAGDSICK: In his concluding paragraph Mr. Zeek has expressed a very hopeful view of the future of high-pressure gas lighting in this country. The high-pressure gas lamp will, of course, find its chief source of competition in electric lamps of high intensity and high efficiency, such as the flame arc. Two years ago Mr. E. N. Wrightington of the Boston Consolidated Gas Company in his lecture during the Johns Hopkins University course in illuminating engineering gave cost data from

which it would seem that the lighting in the class of service for which these large sources are adapted—the illumination of main thoroughfares, display lighting, etc.—can be accomplished at less cost with the long-burning flame arc lamps which have been developed since that time. It would be interesting to know what changes have been made in the performance and operating cost of the high-pressure gas units since these data were presented.

Mr. C. A. B. Halvorson, Jr.: I would like to ask if the price of gas abroad has anything to do with the use of high pressure gas for street lighting? I think it has.

Mr. R. F. Pierce: Regarding the comparative costs of the electric flame arcs and high pressure gas lamps, that is the operating costs, I would say I have no data available of the practise in this country, but such as has been published regarding the comparative operating costs of the two systems is much in favor of the high pressure gas system. Of course, most of this data has come over from England, where the flame arc is a competitor. European practise shows that the high pressure gas lamp is a more economical and satisfactory means of illumination. The prices for gas are somewhat lower abroad than in this country; but when the comparative B. t. u. values are considered, I doubt whether the prices are very much different. I think the price of gas has very little to do with it. What has had the most to do with it has been the activity of the gas companies abroad, who generally occupy different commercial relations with the electrical central stations than those in this country.

Regarding the efficiencies of lamps of this type, the present types of low pressure gas lamps give a maximum light output of about 20 mean spherical candle-power per cubic foot of gas. Slightly higher results have been obtained in certain tests, but this is a good figure. I recently tested some high pressure gas lamps ranging in size from 70 mean spherical candle-power to 2,000 and the average efficiency was about 40 mean spherical candle-power per cubic foot of gas. This would indicate that the efficiency of the high pressure lamps is at least double that of the low pressure lamps.

I might add one statement regarding the efficiency of these lamps. It is very dangerous to base efficiency figures upon the

performance of one particular lamp or installation. Gas lamps must be suited to the gas furnished to them and any considerable variation from the proper equipment may produce serious results. I know of one case where a lamp had been tested in Europe and found to give 52 mean spherical candle-power per cubic foot of gas, and when tested in this country gave an efficiency of but 24 mean spherical candle-power, but by a reasonable amount of experimenting and trial we succeeded in getting the same efficiency as they obtained over there. It is a matter of getting the best equipment for the lamp, and unless this is done the performance will not be such as to justify a sweeping statement regarding the system as a whole.

Mr. R. B Hussey: I might add in regard to the maintenance, that I had occasion to see an experimental installation of high pressure gas lamps a short time ago in Springfield, Mass., and from data given me there I figured that the maintenance would be higher for any cost of gas in excess of 35 or 40 cents than for luminous arc lamp lighting such as is used in Baltimore, New Haven and other places, or for long-burning flame arcs such as are used in Chicago. Of course, this was an experimental installation. As I recall it, the lamps were of the three-mantle type and consumed about 60 cubic feet of gas per hour.

I should like to ask in regard to the color of light from these high pressure gas lamps. In the installations I have seen it seemed to me that the color is more yellow than in the low pressure lamps. I should like to ask also in regard to other installations in this country and also abroad, if the color of the light is not more yellow than that from the tungsten filament lamp and if it is comparable with the yellow flame electric arcs.

Mr. C. W. Jordan: The color of the light given by high-pressure gas lamps is a direct function of the percentage of cerium oxide in the mantle. Mantles containing 0.25 per cent. to 0.5 per cent. of ceria give a light very white in color. Increasing the amount to 1.5 per cent. a reddish light is obtained.

Thus the color of the light from high-pressure lamps can be controlled within certain limits by the manufacturer without great loss in efficiency by simply regulating the ceria content of the mantle.

If it has been noticed that the color is more yellow than that from low-pressure lamps, then for definite reasons the manufacturer has probably specified a mantle giving such a color.

Mr. G. S. Barrows: One thing to be considered in the foreign lamps is that they are not well adapted for use in this country; the weather conditions are entirely different. The lamps which were brought here are most carefully constructed and everything was done to make them satisfactory, but they would not work well under the extreme conditions of temperature and the high winds which we have here.

The average mantle life abroad has been 10 days, while our mantles have given over 45 days.

Regarding the trimming of the lamps at the corner of Broad and Arch Streets, Philadelphia, I would say that they are trimmed once a week. This trimming means that the globes are cleaned once a week and very often this is the only trimming done. Of course our mantle record shows that we are renewing several mantles every week, but some weeks will show no mantles or globes changed at all.

As to the equipment necessary for trimming a lamp—of course if a lamp is up in the air, one must either go up to it or the lamp must be lowered. All the lamps that I have seen (either electric or gas) that were centrally suspended were lowered by means of an arm on the post or other means. Abroad either a flexible tube with a metallic covering or a swing joint is used. In London the lamps are attached to the buildings because the charter of the Gas Light & Coke Co. permits attachment of lamps to any building in London City, but not in Westminster or other parts of London. Cannon Street, I think, is the only one where the lamps are attached to the buildings. In Germany, lamps are suspended above the center of the street, the suspending wires being fastened to the buildings or trolley or lighting poles, and a travelling block used. The blocks are not intricate pieces of mechanism, and the lamps are trimmed very readily. Then, there is another kind of swing joint. Let us assume that the lamp is to be hung about 20 feet above the ground. The post itself is in two parts, the stationary part about 14 feet high, with a yoke at the top. In this yoke is hung the movable part of the

post. This movable part is in general appearance a continuation of the stationary part, and consists of a pipe carrying the lamp at one end and a counterweight at the other. At about the center of this pipe is a suitable connection for fastening to the yoke of the stationary post. When the lamp is to be trimmed, the movable part swings downward, so that the positions of the two ends are reversed, the lamp being at the bottom and the counterweight at the top.

For open spaces, this method of suspension is a very satisfactory one, but in busy streets too much room is required for the swinging of the arm, and it is not as satisfactory a method of suspension as that in which a block is used.

SOME REFLECTING PROPERTIES OF PAINTED INTERIOR WALLS.*

BY CLAUDE W. JORDAN.

The determination of the reflection co-efficients for various types of wall papers has received some attention and the results obtained have often proved of great assistance to the illuminating engineer in working out specific interior lighting problems.

Within recent years there has been a great advance in the use of painted walls in securing harmonious effects in the decoration of the interiors of dwellings and public buildings, but apparently there has been little or no work published of determinations of the reflecting properties of the various types of paints used. The increased use of painted finishes is, in all probability, due to the durability of the surface, ease in cleaning and replacing, and the demand for greater simplicity in design, although in special cases some very intricate work has been done with wall paints. Incidentally there is a factor which is of great importance, and that is the sanitary value due to the inherent composition of the liquid paint, the fact that the surfaces can be cleansed by washing, and also the character when dry. This fact has been substantiated experimentally[1] by exposing test boards, some of which were painted and others covered with wall paper, to equally unsanitary conditions; after a definite period the number of colonies of bacteria which developed from the washings of the surfaces was determined on the usual agar-agar, bouillon and gelatine culture mediums. In all cases the results were decidedly in favor of the painted surfaces, showing that the oxidized oil surface harbors little dust and the associated bacteria which may be either pathogenic or non-pathogenic.

Generally when paints are used, light colors are selected; and when they become noticeably dirty, attention is attracted to the fact that for sanitary and other reasons they should be cleaned.

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

[1] Dr. F. F. Gwyer, Cornell Univ. Med. College, New York City.

With these factors in favor of painted walls, the future seems quite bright and opens up a wide field of investigation of the physical properties which are of interest to the illuminating engineer.

APPARATUS USED.

The apparatus used in making reflection determinations was, with the exception of a few minor details, similar to that employed by Mr. Gilpin[2] in a recent investigation on the effect of varying the incident angle upon the co-efficient of diffused reflection. This is shown diagrammatically in figure 1.

A sharply defined spot of light is thrown upon a test surface and the reflected light in the plane of the incident ray is measured

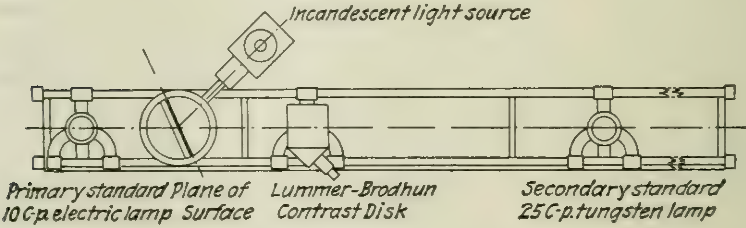


Fig. 1.—Plan of apparatus.

upon a photometer bar. Thus a photometric curve of the reflected light is obtained.

In calculating the efficiency of reflection, it is necessary to determine the total amount of light falling upon, and the total amount of light reflected from, the surface, the ratio being the co-efficient of reflection in that direction. The first quantity is obtained by determining (a) the effective center of the light source from the axis of the surface in feet, (b) the area of the spot light in square feet, (c) the intensity of the light source in candles and (d) the angle between the incident ray and the normal.

The computation of the incident light in lumens from the above is as follows:

[2] TRANSACTIONS of the Illuminating Engineering Society, vol. v, p. 855, Dec., 1910.

$$\text{Incident lumens} = \frac{A \times C.\ P. \times \cos.\ \theta}{d^2}.$$

Where A = area of spot light,

C. P. = intensity of source,

θ = incident angle,

d = the distance from the effective center to the axis of the test surface in feet.

The quantity of reflected light is calculated by plotting a photometric curve about the spot light and the average candle-power in ten equal zone angles determined. This value multiplied by 6.28 gives the reflected lumens.

The light source used for making these determinations was an upright incandescent gas lamp having an artificial-fiber-base mantle, properly seasoned to give constancy of illumination and used with a gas of a constant heating value. The candle-power was checked at short intervals and showed very little variation.

The primary standard of light was a 10 candle-power carbon filament electric lamp and the secondary standard was a low-voltage tungsten lamp of 2.5 candle-power.

TYPES OF WALL PAINT.

In general there are two types of wall paints used for interior work, those which when dry have a very flat finish and those which retain a glossy finish. There are, of course, many intermediary finishes such as (a) "dead" flat, (b) semi-flat, (c) glossy, and (d) highly enameled. But these simply modify the reflecting differences between the extremes, namely, flat and highly glossy finish.

An absolutely flat paint is not commercially practicable if the physical advantages of paints are to be realized, as there must be a certain amount of oxidized oil present to hold together firmly the paint particles and to act as a protector from dust. Water color paints come nearer to being dead flat than do any other kind, but these require constant renewal, as they cannot be successfully cleaned without deterioration of the decoration.

An analysis of a fairly good commercial flat paint is as follows:

	Per cent.
Pigment by weight	67
Liquid or vehicle by weight	33

COMPOSITION OF LIQUID:

Linseed oil	20
Varnish	20
Turpentine	60

The adherence of the pigment is dependent upon the linseed oil and the varnish which, when dry, form a hard glossy surface, but as the absolute amount of liquid present is small and 60 per cent. volatilizes, an apparently flat finish is obtained.

A glossy paint on the other hand may be represented by the following formula:

	Per cent.
Pigment by weight	50
Liquid by weight	50

The liquid in some cases is varnish combined with waxes or in others, when a less glossy paint is desired:

	Per cent.
Processed linseed oil	60
Turpentine	40

The finish of a paint has a marked effect upon the diffusion and efficiency of a reflecting surface, as will be subsequently shown. For purposes of comparison, two white paints of nearly the same pigment composition were selected, one of which dried to a flat finish while the other retained a highly glossy finish. These were painted on smooth plastered test surfaces, and the co-efficient of reflection determined with the incident light in each case at 0 deg., 15 deg., 30 deg., 45 deg. and 60 deg. to the normal of the plane. Fig. 2 shows the reflection curves obtained at each angle from the flat finish paint. It will be seen that as the angle of incidence increases, the efficiency of the surface as a reflector becomes slightly greater. The diffusion curve becomes slightly elliptical as the angle of incidence becomes less, shifting very slightly toward the direction of the incident ray. The average efficiency of this type of paint at the incident angle tested, was 63.3 per cent.

Fig. 3 shows the reflection curves obtained at the various angles from the glossy finish paints. These curves well show the effect of specular or regular reflection at each incident angle. It will be

noted that the curve representing the 60 deg. incident ray shows very good diffusion to the 30 deg. angle on the left, at which point the candle-power is suddenly increased by the specular reflection from the oil surface of the paint. It is well known that if light rays passing through a homogeneous medium are disturbed by the introduction of a substance of different optical density, the rays undergo a sudden change in direction at its surface, each ray splitting into two—a reflected and a refracted ray. The regular laws of reflection and refraction hold in that the reflected and refracted rays both lie in the plane of incidence. The angle of

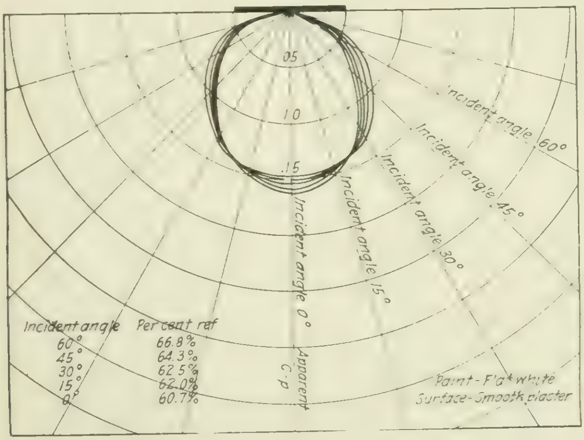


Fig. 2.—Reflection from flat finish paint in plane of incident angle.

reflection is equal to the angle of incidence and the angle of refraction bears the following relation to the angle of incidence.

$$\frac{\text{Sin } \theta}{\text{Sin } \theta'} = n,$$

in which $\theta =$ the angle of incidence,

$\theta' =$ the angle of refraction,

$n =$ the index of refraction in terms of the surrounding medium.

The amounts of light reflected and refracted depend upon the degree of polarization, the incident angle and the index of refraction of the transparent medium, the reflection becoming greater the greater the incident angle.

The light which is reflected from the surface is, in general, of the same color as the light source, while that which is reflected by the pigment depends upon the selective absorption of that pigment and may be influenced by the color of the oil filament. These facts may be of some importance in the use of any given paint when uniformity of color is especially desired. To illustrate this point, both slits of a spectrometer were set at the same width and the light source was adjusted so that the reflected light from two mat surfaces was of equal intensity. The distribution of white light in the spectrum could then be conveniently represented by a straight line (a), fig. 4.

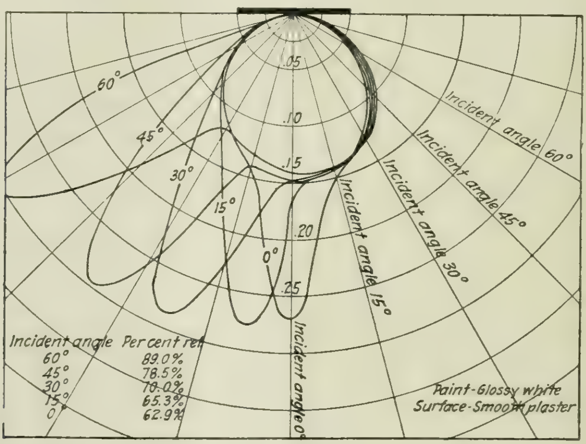


Fig. 3.—Reflection from glossy finish paint in plane of incident angle.

The distribution of diffused light from (b), a red painted surface of flat finish, and (c) a green painted surface of flat finish, were then obtained. Similarly colored surfaces having glossy finishes gave the distribution shown in fig. 5 when the surface was turned at the proper angle with relation to the incident angle, so that specularly reflected light entered the slit.

If the paint pigment reflected monochromatically, the effect of dilution with white light would tend only to change the saturation, or, in some cases, to dilute it to such an extent that it appeared nearly the same color as the light; but if the light sources are of variable spectral compositions, then the dilution may tend to change the hue as well as the saturation; and if it is diluted

sufficiently it appears nearly the same color as the light source. The total dilution would occur if the light source were sufficiently

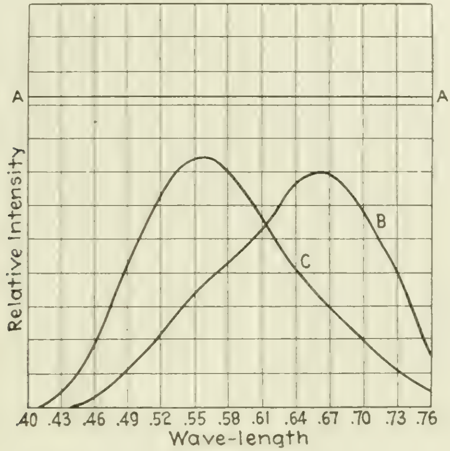


Fig. 4.—Selective reflection of flat paints.

large to entirely prevent diffused selectively reflected light from entering the eye. There are, however, no monochromatic paints on the market and some marked changes in hue are noticeable in

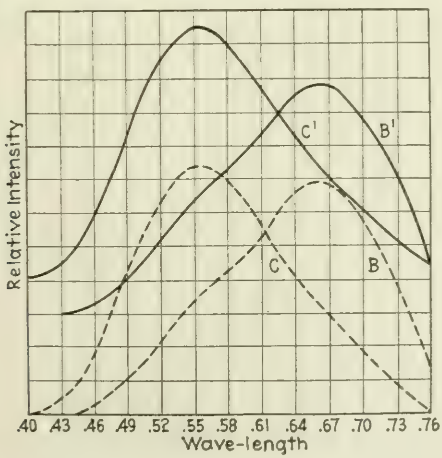


Fig. 5.—Dilution of selective reflected light with specularly reflected white light.

colors of complex compositions when mixed even with white light and especially with variable spectral sources. Such paints

would, however, have a great advantage in that the color of the diffused reflected light would be affected only in intensity by different light sources.

Fig. 6 shows the distribution of reflected light from sage-green paints of flat and glossy finishes. The reflection from the flat finish at the 60 deg. incident angle is 34 per cent., while the glossy finish at a similar angle shows 62.5 per cent. Assuming that the composition of the oxidized oil remains constant, or nearly so, the lower the coefficient of diffused reflection from a flat finish paint, the greater the percentage difference between it and a

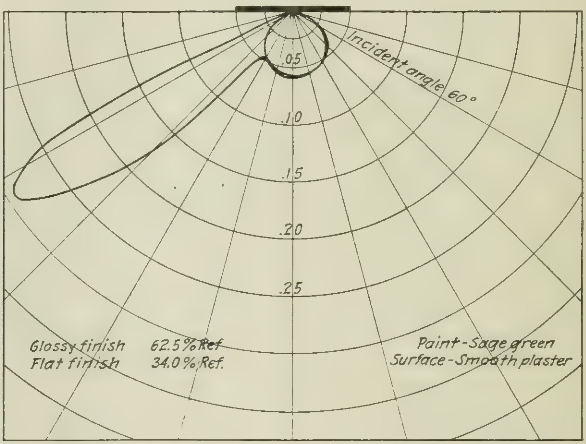


Fig. 6.—Distribution of reflected light from sage green paints in plane of incident angle.

similarly colored paint with an oil finish. If a diffuse reflector is 100 per cent. efficient, then the specular reflection from a similar glossy paint could not increase the efficiency, but as the co-efficient of diffused reflection becomes lower, the percentage difference between the flat and glossy finishes becomes greater as specular reflection remains constant or nearly so.

Several distribution curves of the reflected light were made in a plane at right angles to the plane of the incident rays of light and in the case of a very flat finish paint gave practically the same results as those obtained in the other plane.

The following results were obtained:

Incident angle Deg.	Reflection in plane of incidence Per cent.	At right angles Per cent.
60	66.8	64.2
45	64.3	64.0
30	62.5	63.5
15	62.0	62.5
0	60.7	61.8

A flat white paint on smooth plastered surface was used.

In the case of a glossy paint the results were quite different as would be expected. In the plane at right angles to the plane

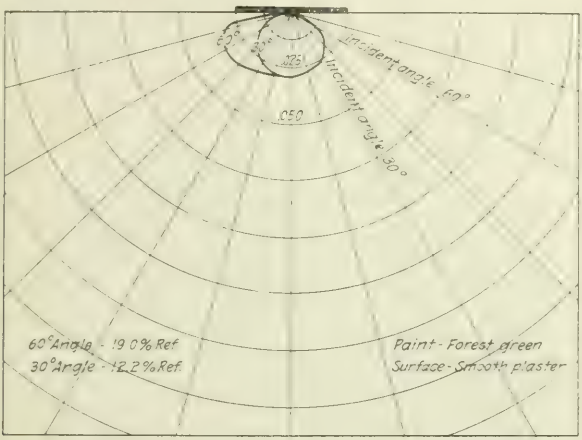


Fig. 7.—Showing reflection from semi-matt paint in planes of incident angles.

of incidence, diffusion curves were obtained almost similar to those of a flat finish paint. The results were as follows:

Incident angle Deg.	Reflection in plane of incidence Per cent.	At right angles Per cent.
60	89.0	62.0
45	78.5	62.9
30	70.0	63.5
15	65.3	67.0
0	62 0	64.0

Fig. 7 shows the distribution of reflected light from a semi-glossy paint with incident angles of 60 deg. and 30 deg. It will be noted that on the more oblique angle there was some little distortion of the curve due to specular reflection, while at 30 deg. the reflection was fairly diffused. This was quite apparent when the test surface was held in such a position that the light came

from an oblique angle, for the color sensation was nearly white. When held in a position so that the incident light was normal the surface appeared to be a good diffuser and there was no apparent oil surface which would give specular reflection. The thickness of the oil coating, then, determines somewhat the angle at which specular reflection is most noticeable.

PHYSICAL CHARACTERISTICS OF WALL SURFACES.

The physical structure of wall surfaces affects somewhat the distribution curve of the reflected light, the amount depending upon the nature of the finish. There are two general types of surfaces commonly used, the smooth plastered finish and the

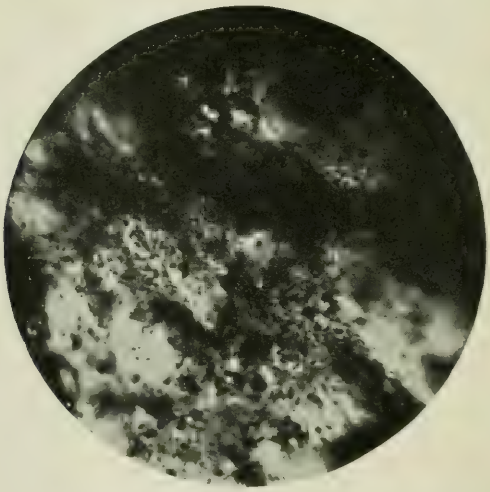


Fig. 8.—Micrographic enlargement of rough plastered walls.

rough plastered finish. A very homogeneous surface can be obtained by using ordinary plaster, while the roughening effect can be made to any degree desired by controlling the size of the sand particles used.

Fig. 8 is a micrographic enlargement of a rough finished wall and gives a general idea of the reflection effect when the light rays come from a very oblique angle. This surface, however, was not painted when this photograph was taken.

Fig. 9 is a micrographic enlargement of a smooth finish wall and of the same magnification as fig. 8. This surface is fairly

smooth and the very slight irregularities, imperceptible to the naked eye, would largely disappear after receiving several coats of paint, thus leaving a very homogeneous layer of extremely fine paint particles.

For the purpose of accurate comparison, the flat and glossy paints used on the smooth wall for illustrating the reflection differences of the two finishes were painted on rough-plastered test plates.

Fig. 10 shows the reflection curve and the efficiencies obtained from the glossy finished paint on this type of surface with the incident angles of 60 deg., 45 deg., 30 deg., 15 deg. and 0 deg.

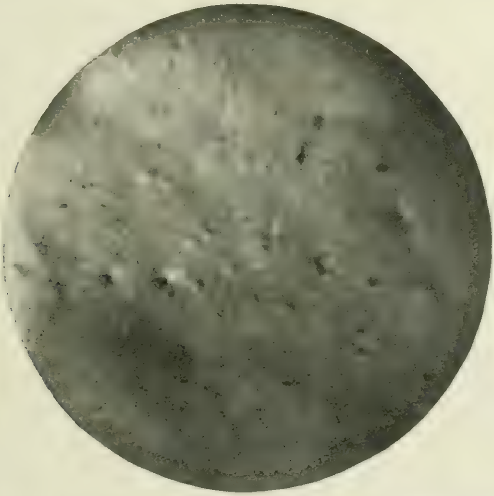


Fig. 9.—Micrographic enlargement of smooth plastered wall.

to the normal of the plane. The general effect of specular reflection is still quite prominent, but the diffused light in the direction of the incident angle is slightly increased. On very rough surfaces the specular reflection at an angle equal to the incident angle becomes less and a mixture of diffused and regular reflected light is noticeable in the direction of the incident rays. This can be readily accounted for when considering the microscopic structure of the surface and taking into account the reflection laws.

Fig. 11 shows the reflection curves and efficiencies obtained from the flat finish paint on the surface with the incident light

from the various angles. The curves have all shifted slightly towards the direction of the incident rays, as was noted in the case of diffused reflection from the glossy paint.

In considering the physical characteristics of walls it may also be of interest to mention something regarding the physical properties of the coloring particles composing the pigment. It is well known that these particles are extremely small, for they cannot be individually distinguished by the naked eye; the smaller particles require the use of a high-powered microscope to clearly distinguish their form. The actual size of the pigments has been determined by several investigators and has been found

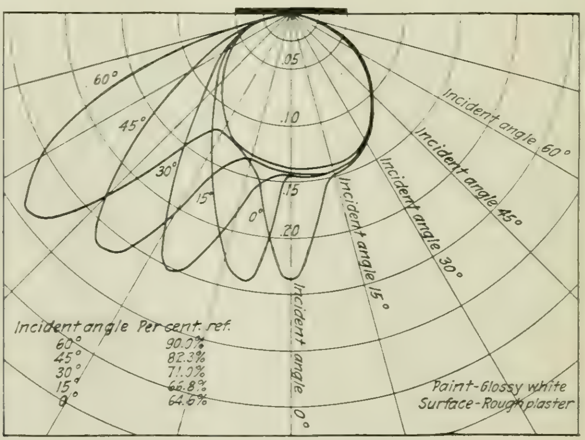


Fig. 10.—Reflection from glossy finish paint in plane of incident angle.

to range in diameter from 0.0003 mm. for the smallest particles of sublimed white lead to as high as 0.10 mm. for asbestine. If these small particles could be made to properly adhere to each other without the use of any binding medium which would tend to disturb their reflecting properties, the reflection of light from the surface would closely follow Lambert's cosine law. Investigations made by Wright[3] using various finely divided oxides held together by subjecting the mass to a high pressure showed that this was true within a small percentage error.

Fig. 12 is a micrograph (about 1200 diameters magnification)

[3] H. R. Wright, "Photometry of the Diffused Reflection of Light on Matt Surfaces," *Philosophical Magazine*, Feb., 1900.

illustrating the nature of the reflecting surface. The individual appearance of the particles can be perhaps better observed by the micrograph shown in fig. 13, in which the paint was spread on a glass slide to form an extremely thin film.

Naturally from the size and irregular arrangement of these particles, a microscopic matt surface is formed giving good diffusion of light provided they are not covered with a refracting oxidized oil.

The degree of subdivision of the pigment has also a marked effect upon the resulting color and reflection efficiency of the paint. For instance, natural barium sulphate when formed into

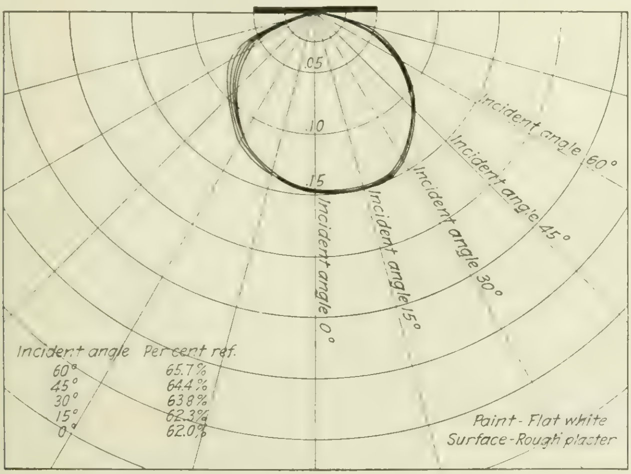


Fig. 11.—Reflection from flat finish paint in plane of incident angle.

a paint in linseed oil, is practically transparent due to the size and nature of the particles. Chemically precipitated barium sulphate on the other hand, which is composed of extremely fine particles, when ground in linseed oil forms a fairly opaque white paint.

This holds for a great variety of pigments and the manufacturers of paints have found that in order to accurately reproduce a given color they must hold closely to the same pigment size. This is accomplished by preparing the pigments by the same methods at the intervals they are required.

The effect was reproduced experimentally by taking paints

having rather large pigment particles and subdividing these by crushing. Quite appreciable changes in the tint and the reflectiton efficiency followed.

The exact physical phenomenon has not been accurately determined, but it is supposed, for example in the case of natural barium sulphate, there is no scattering of the light as the pigment is composed of more or less transparent crystals, and consequently the effect upon the eye is that of a transparent medium. When the surfaces become very irregular by crushing the particles or using the chemically precipitated substance, the light is

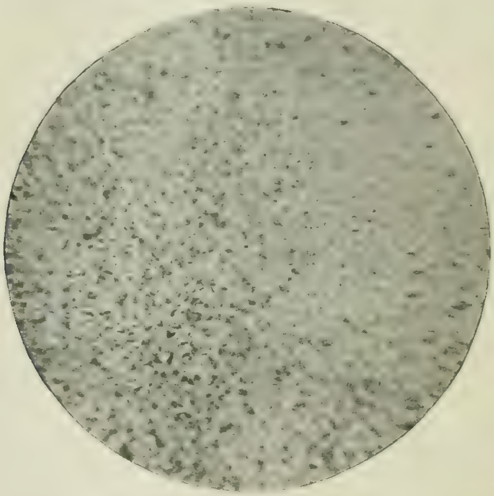


Fig. 12.—Micrograph showing nature of painted reflecting surfaces. (Magnified about 1200 diam.)

well scattered due to the great number of irregular planes thus presented for reflection and refraction.

The distribution of the reflected light can be modified slightly by the method of applying the paint. In painting surfaces by means of the usual brush, if the paint is not of the proper consistency, the liquid very volatile, or the brush defective, a pronounced streak effect results which is undesirable from an artistic point of view alone. This streaking effect distorts the curve of the reflected light in a manner almost similar to the rough surfaces provided the streaks are at right angles to the plane of the incident light.

Fig. 13.—Micrograph showing nature of individual paint particles. (Magnified about 1200 diam.)

The following table shows the percentage reflection from various colored paints on smooth test plates in the planes of 60 deg., 30 deg. and 0 deg. incident angles.

Sample No.	Color of paint	Finish	Percentage reflected at incident angle of 60 deg.	30 deg.	0 deg.	mean
1	White	Flat	66.8	62.5	60.7	63.4
2	White	Flat	71.5	68.5	66.2	68.7
3	White	Glossy	89.0	70.0	62.9	74.0
4	Cream	Flat	55.6	53.8	51.0	53.5
5	Ivory	Flat	52.8	50.0	48.0	50.0
6	Ivory	Glossy	77.5	62.3	52.0	63.9
7	Aurora Yellow	Flat	29.3	30.5	29.8	29.9
8	Fresco Green	Glossy	32.6	18.8	11.0	20.8
9	Pale Azure	Semi-glossy	36.8	32.3	28.4	32.5
10	Bright Sage	Flat	32.6	33.0	32.0	32.5
11	Pompeian Red	Flat	10.0	8.2	7.5	8.6
12	Forest Green	Semi-glossy	19.0	13.5	12.2	14.9
13	Silver Gray	Flat	20.5	18.2	17.3	18.6
14	Crimson	Glossy	28.2	13.8	4.0	15.3
15	Crimson	Flat	6.0	5.5	4.9	5.5
16	Nile Green	Glossy	59.1	41.2	33.3	44.5
17	Silver Gray	Semi-glossy	35.0	29.8	24.5	29.8
18	Sky Blue	Glossy	54.3	31.2	25.4	37.0
19	Sage Green	Glossy	62.5	48.4	39.5	50.1

The reflection coefficients are those obtained when the incident light has the spectral composition of an incandescent gas lamp and in some cases would probably differ materially if, for example, a spot of light from a tungsten electric lamp, having a different spectral composition, was used. The apparent colors to the eye would then differ somewhat.

SUPPLEMENTARY.

It was recently suggested that the character of the incident light as to diffusion might affect the efficiency of the reflecting surface to a marked degree. The thought was that with light rays coming from a greater number of directions, that is diffused light, they would be reflected more efficiently than the direct light, such as was used in making the determination described. In order to investigate this point the intensity of the light source in the apparatus was increased about 30 per cent. by raising the gas pressure, and a small circular piece of highly diffusive opal glass inserted in the opening of the screen, thus allowing a spot of light highly diffusive in its nature to fall upon the test surface. The intensity of the diffused light was 2.5 candle power against 13.5 for the direct light. The reflection coefficients of white paints, flat and glossy, on smooth surfaces were then determined and gave the following results:

DIRECT LIGHT.

	Reflection coefficient of incident angle of		
Paint	60 deg. Per cent.	30 deg. Per cent.	0 deg. Per cent.
Flat white	66.8	62.5	60.7
Glossy white	89.0	70.0	62.9

DIFFUSED LIGHT.

Flat white	64.1	63.3	59.8
Glossy white	89.3	70.5	61.0

The efficiencies were in all cases in very close agreement and the reflection curves were almost identical in shape, showing that for ordinary painted walls the reflection of light is not materially dependent on whether the light is highly diffused or direct from a point source.

DISCUSSION.

Mr. T. W. Rolph: It is stated that the quantity of reflected light is determined by the usual method of averaging the candle-power values at the centers of zones of equal flux. Presumably in the curves shown in fig. 10 the average is taken on each side of the curve. I would like to ask what assurance we have that these curves, which were made in the plane of the angle of incidence, represent the average of all the curves?

Mr. W. J. Cady (communicated): In regard to Mr. Jordan's paper on the reflection from painted walls, I think it should be pointed out that the figures which he gives should be used with a great deal of discretion. For instance the figures which he gives on the fifteenth page of his paper do not represent the coefficients of reflection of the surfaces tested nor do they correctly represent the percentage of reflected light. For the diffusely reflecing surfaces they are undoubtedly very close to the true reflection coefficients but for the glossy surfaces they are not representative.

It is not correct to calculate the lumens given out from a light source or secondary reflecting surface by using a lumens constant, as is done on the third page, unless the distribution curve represents the average of all planes. In case of a matte surface the error involved would be slight and in the case of a perfectly diffusing surface the method would be correct. But for the case of a reflecting surface such as a glossy paint the error will be quite large. This is brought out forcibly in Mr. Jordan's paper, on the sixth page, for if he had continued the tests to have included an incident angle of 75 deg., the per cent. reflection would have been 100 per cent. or over, which of course would be out of the question. Also on the ninth page the tests on the glossy paint in the two planes, one including the plane of incidence and the other at right angles to it, show that it is incorrect to figure the coefficient of reflection from such a surface by testing in but one plane. In this case it is shown that with an incident angle of 60 deg. the figure for the reflection in the plane of incidence is 89.0 per cent., while in the plane at right angles to this it is 62 per cent. The fact of the matter is that the true value lies somewhere between these two figures. It, however, is

not an average of the two but is nearer the 62 per cent. than the 89 per cent. The true value could be obtained by determining the distributions in a sufficiently great number of planes to get a correct average.

Mr. Claude W. Jordan (in reply): Paints, termed by the same name, but made by different independent manufacturers, show quite a variation in their reflection coefficients. I have found cream colored paints from several manufacturers to vary as high as 10 per cent. It can thus be seen that the reflection coefficients given in the table do not hold absolutely for the specific paints when obtained from different manufacturers.

A question has been raised as to the irregularity of the 60 deg. incident angle distribution curve at a point marked 60 deg. on the left (fig. 10). This is due to the specular reflection from the oil surfaces of the paint, as described in the text.

As to the method of obtaining the zero degree incident angle curve, the light source is fixed in position normal to the test surface and both are revolved around a central axis. Of course it is practically impossible to obtain the candle-power at zero deg. and this is interpolated. It can, however, be approached very closely, to within 10 deg., without interfering with the reflected light incident on the comparative disk.

Regarding Mr. Rolph's question—the curves shown are those obtained in the plane of the incident angle. As described on the eighth page of the paper, for diffusely reflecting paints there is little difference in efficiency if the curves are made in a plane at 90 deg. to the plane of the incident angle.

In dealing with paints that reflect specularly, there is of course a marked difference in the coefficient of reflection obtained in the plane at 90 deg. and that obtained in the plane of the incident angle.

This difference is shown in the table on the ninth page.

Just what the average reflecting power for this type of paint is in a great number of planes I am not in a position to state.

In answer to Mr. W. J. Cady's communicated discussion regarding the usefulness of the reflection coefficients given for the various colored surfaces—it has already been forcibly brought

out in the paper that these are the efficiencies obtained in the plane of the incident light rays and should be treated as such.

The method of computation of assuming the intensities the same in an infinite number of planes and thus calculating the lumens was used, and while it admittedly does not represent the true lumens in the case of a paint covered with a refracting oil, it serves as an accurate criterion for obtaining the efficiency of the reflecting surface. The coefficient of diffuse reflection is obtained fairly accurately by interpolating the curve following the cosine law and the coefficient of specular reflection is the relative intensity of the reflected light at an angle equal to the incident angle of the source. The average of the two is the efficiency in the plane under investigation. Thus the curves shown bear a practical relation to the average intensity of the reflected light in the plane under investigation.

In the case of the pigment which is not covered with an appreciable layer of a refracting oil, the average coefficients given are closely correct for any incident angle except possibly the very oblique angles slightly less than 90 deg. to the normal of the plane when calculated by the lumen method.

The distribution curves and efficiencies of the reflected light were purposely given in the plane of the incident light source to demonstrate the variation when this angle is changed and also to show that in practise a great increase in intensity on a working plane can be obtained when the reflecting surface bears a proper relation to the light source.

The average efficiency of a surface in a great number of planes was discussed verbally by Mr. Rolph, and it is true that this is not nearly as great as that shown in the single plane of the incident angle when the surface reflects specularly, the exact amount being variable, depending on the coefficient of diffused reflection of the surface. In order to show that such was the case, distribution curves were made at 90 deg. to the plane of the light source. The results obtained are shown on the ninth page of the paper.

Owing to the lack of time a greater number of angles was not investigated.

A 100 per cent. efficiency at the 75 deg. incident angle could

not possibly be realized, for when light rays pass from a medium of less to greater optical density, regardless of the incident angle, there is always a reflected and a refracted ray, the relative amounts depending on the incident angle refractive indices, etc. While at 75 deg. there is more light specularly reflected than at 60 deg., 100 per cent. efficiency is not realized, for diffused reflection can be observed, and this always involves absorption. If all of the incident light were specularly reflected, the efficiency measurement of the surface would simply involve measurements of intensity, following the inverse square law.

THE ENGINEERING PRINCIPLES OF INDIRECT AND SEMI-INDIRECT LIGHTING.*

THOMAS W. ROLPH.

This paper is an attempt to analyze from an engineering standpoint, the problem of indirect and semi-indirect lighting. The aim is to formulate the advantages of this class of lighting and to determine the engineering requirements of the light-units, which will obtain these advantages to their fullest degree and most efficiently. Certain considerations, brought out by the writer in a paper[1] before the Pittsburgh section of the Society, in May, form a logical part of this subject and will be repeated here in abstract.

The term indirect lighting is used to refer to lighting systems in which no light is received on the plane of illumination directly from the light-units (*i. e.* the lamps and their equipment). The term semi-indirect lighting refers to lighting systems in which only a small part of the illumination is received directly from the light-units. The term direct lighting is used in contra-distinction to the above to refer to systems in which a large part (in rare cases all) of the illumination is received directly from the light-units.

The illumination received from the majority of lighting systems can properly be treated as made up of two parts—the direct component and the indirect component. With totally direct or totally indirect lighting, only one of these components is present. Considering the utilization of light after it leaves the light-unit, the efficiency of the direct component is obviously 100 per cent., while the efficiency of the indirect component, due to absorption of the ceiling and walls is usually less than 50 per cent. Consequently, comparatively low illumination efficiency is ordinarily obtained with lighting systems in which the indirect component is high. This is the greatest drawback to the use

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

1 TRANS., I. E. S., June, 1912.

of such systems. There are also, however, certain minor disadvantages, the principal of which are too much light on the walls causing depression of visual function, the undesirable appearance of a brightly lighted ceiling and lack of perspective due to lack of shadows. These minor disadvantages can be largely overcome by proper design. The walls should be dark in color if the highest visual efficiency is to be obtained with this class of lighting. Bright spots above the light-units can be largely avoided by obtaining a wide distribution of light on the ceiling. A small direct component will help the appearance by relieving the contrast between a dark light-unit and the brightly lighted ceiling. A small direct component also aids in giving perspective.

Low illumination efficiency is the only important and unavoidable disadvantage of lighting systems having a high indirect component of the illumination. The advantages of a high indirect component should be sufficient to justify this comparative inefficiency. These advantages are of two classes—esthetic and engineering. The esthetic advantages will not be considered here.

The engineering advantages of a high indirect component are all due to the great increase in size of the light-giving (or reflecting) areas. This increase in size insures a low intrinsic brilliancy of all visible surfaces and a highly diffused (or multidirectional) character to the light, which produces useful illumination. Low intrinsic brilliancy of surfaces within the range of vision increases visual efficiency and comfort. A highly diffused character to the illumination tends to eliminate specular or regular reflection from surfaces worked on and to eliminate sharp and deep shadows. Whether these advantages justify the comparatively high cost of operation of an indirect or semi-indirect system of lighting must be decided for each particular installation. The absence of specular reflection in the direction of the eye and of sharp and deep shadows are essential requirements of good illumination for surfaces on which close visual work is to be performed; but these requirements can often be met by proper placement of direct light-sources, as well as by the diffusion of a high indirect component. There are certain classes of service, however, for which the preponderance of evidence seems to justify the greater cost of an indirect or semi-indirect

system. In this class are all rooms in which close visual work is to be performed on surfaces which are not permanently located or on surfaces which may be permanently located, but necessarily in undesirable positions with reference to the light-sources. Such rooms are drafting-rooms, offices, school-rooms, reading-rooms, etc. The use of a high indirect component is also a good method of illuminating such rooms as picture galleries where the desideratum is vertical illumination on the walls with minimum specular reflection.

Since the use of a high indirect component requires that the efficiency of direct lighting be sacrificed, it is important to obtain in return, the highest possible value in illumination advantages. The question, therefore arises, What are the engineering requirements of the light-unit which will obtain the advantages of a high indirect component as fully and as efficiently as possible? The consideration of this question naturally divides itself into two parts (1) What proportion of the light should be direct? and (2) What should be the photometric distribution of the light comprising the indirect component?

PER CENT. DIRECT COMPONENT.

This question was treated in a paper delivered by the writer before the Pittsburg section in May. The conclusion was reached that the most desirable degree of elimination of specular reflection from working surfaces, of sharp and deep shadows, and of glare from the light-unit requires that the direct component be not over 15 per cent. of the total illumination. From the standpoint of specular reflection, the argument is that if any lighting proposition justifies the high operating cost of a comparatively large indirect component, it justifies making the per cent. direct component such as to eliminate specular reflection as much as possible; any uni-directional light will cause specular reflection; the light-unit should therefore be no brighter than the maximum brilliancy of the ceiling providing this brilliancy is reasonably low; the illumination at any point on a working surface will then be obtained in no greater degree from the light-unit than from an equal nearby area of the ceiling and the glare from specular reflection will be no greater than in the case of totally indirect lighting; the direct component which will give this brilliancy of

light-unit was found to be approximately 12 per cent. under average conditions. From the standpoint of sharp and deep shadows the value of 15 per cent. direct illumination was determined, largely as a result of a series of observations on the effect of various shadows on working surfaces. From the standpoint of glare effect from the light-unit itself, the most desirable criterion seemed to be that of intrinsic brilliancy no greater than the ceiling, the same as adopted for the best degree of elimination of specular reflection.

In order to supplement this reasoning, a further series of observations was made under the actual conditions of illumination with varying percentages of direct and indirect components. These were made to determine the per cent. direct component at which shadows and specular reflection from working surfaces are perceptible, perceptibly annoying and decidedly annoying. A light-unit was used in which were two lamps, one giving direct light only and the other indirect only. The lamps were on separate circuits so that by varying the voltage of each circuit, the illumination at any point on the working plane could be obtained in any desired proportions of direct and indirect, while the total illumination could be kept constant. Engineers familiar with illumination requirements were selected as observers on the theory that the opinions of such men in matters of this nature are of more value than the opinions of laymen.

The room used was 20 feet 6 inches (6.25 m.) square and 10 feet (3.05 m.) in height. The finish of the ceiling was white calcimine and of the walls light green calcimine. The walls, however, were broken on three sides by four windows per side while the fourth side of the room was a dark-colored wooden partition with panels of maze glass. The light-unit was suspended in the center of the room. Fig. 1 is a photograph of the unit. The indirect component was obtained by using a 12 inch (30.48 cm.) inverted bowl-shaped prismatic reflector with a 250-watt clear tungsten filament lamp. The lamp was placed in a position such that a distribution of light considerably wider than the extensive distribution was obtained. It was thought that by thus obtaining practically uniform illumination over a considerable portion of the ceiling, the indirect component would be

more nearly representative of lighting systems in which more than one unit is used. The outside of the reflector was surrounded by black cloth. Directly below this reflector was suspended the direct unit consisting of an inverted 15 inch (38.1 cm.) shallow light-density opal reflecting shade with a 100-watt clear tungsten filament lamp and a white cardboard reflecting surface above. All the direct illumination was obtained by light transmitted through the opal reflecting shade. The diffusion of light over the surface of the shade was nearly perfect and represented very closely what is often obtained in practise with semi-

Fig. 1.—Light-unit used for observations on specular reflection and shadows.

indirect lighting. All upward light was cut off by black cloth which was allowed to hang over the edge of the reflector cutting off also, most of the direct light emitted toward the walls. The upper edge of the indirect reflector was 2 feet 3 inches (0.68 m.) from the ceiling, while the bottom of the shade used for direct light was 3 feet 5 inches (1.04 m.) from the ceiling. The voltage across each lamp was measured be means of a standard laboratory voltmeter. Battery current was used, greatly facilitating voltage regulation.. The first step was to determine the voltage-illumination curves for the direct and indirect components, meas-

uring the illumination at points on the horizontal plane selected as the points for observation. These curves determined the voltage setting for obtaining at the observation points any desired intensity of illumination either direct or indirect. The curves were frequently checked during the observations.

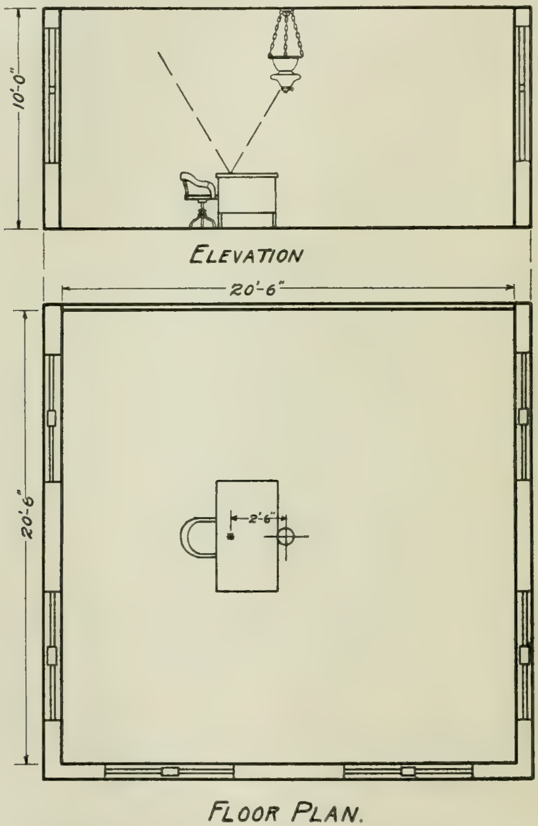


Fig. 2.—Relative positions of light-unit and desk in observations on specular reflection

For the observations on glare, two kinds of paper were used, these being pages from *Good Lighting* and the *Saturday Evening Post*. The paper used in *Good Lighting* is representative of that used in a large number of magazines and has an appreciable glaze to the surface. While many magazines are printed on paper having a still higher degree of glaze, still this paper can be taken

as fairly representative of the maximum degree of glaze on papers in common use. Paper of this character forms a considerable portion of that found in any rooms in which an appreciable amount of reading of printed matter is carried on. In offices such paper is not so much in evidence, although by no means uncommon. In drafting-rooms a still higher degree of glaze is obtained in the case of tracing cloth. The paper used in the *Saturday Evening Post* is considerably more diffusely reflecting. The portion of the magazine selected for observation was printed in 7-point Roman, condensed type. All observations were made on a horizontal plane 2 feet 6 inches (0.76 m.) above the floor. The observer was seated at a desk in such a position that the maximum degree of specular reflection due to the direct component was received by the eye from the surface of the desk. Fig. 2 shows this position. The observer was first given sufficient direct light to observe at exactly what spot the glare effect appeared. The illumination was then made totally indirect and the per cent. direct component was increased by successive steps from 0 per cent. to 100 per cent. The total illumination was kept at 3.0 foot-candles at every step. By using considerable variation in the size of steps, the observer was at all times kept ignorant of the proportions of the direct and indirect components. Each observer was given the following instructions:—

All observations are to be made in the spot of regular reflection.

Comparisons with other portions of the page and with the opposite page are permissible. State points at which specular reflection is

Perceptible,
Perceptibly annoying,
Decidedly annoying,
Sufficient to prevent reading the printing submitted.

Be guided by the following considerations:

Perceptible: This is simply a brightness comparison. The size of print does not affect it. The specular reflection should be perceptible as a spot on the paper, *i. e.*, it should be due to the direct component. With totally indirect lighting, it is possible by tipping the paper, to perceive a slight degree of specular reflection, but this should be neglected.

Perceptibly annoying: The judgment should be based on reading the printing submitted.

Decidedly annoying: The judgment should be based on reading the printing submitted.

Sufficient to prevent work: Sufficient to prevent reading the printing for more than 15 to 30 seconds.

As stated in these instructions, a certain degree of glare effect was observable with totally indirect lighting, viz., there was appeciable difference in the degree of comfort in reading, between the positions of the paper in which specular reflection of the bright portion of the ceiling was and was not obtained from the paper. This was observable with both kinds of paper. Table I gives the observations in complete detail so that all variations can be seen. The last point was never reached. All the ob-

TABLE I.

OBSERVATIONS ON SPECULAR REFLECTION FROM WORKING SURFACES.

	Per cent. direct component of the illumination at which specular reflection is					
	Perceptible		Perceptibly annoying		Decidedly annoying	
Observer	Observation	Average	Observation	Average	Observation	Average
Observations made on "Good Lighting."						
W. J. Cady	20		30		.60	
	15		30		50	
	15	17	25	28	45	52
W. A. Dorey	10		20		50	
	5		20		50	
	5	7	20	20	40	47
H. W. Shalling ..	5		25		45	
	5		35		65	
	5		25		40	
	5	5	25	28	55	51
Average		10		25		50
Observations made on "The Saturday Evening Post."						
W. J. Cady	40		50		95	
	40		65		90	
	35	38	55	57	90	9[illegible]
W. A. Dorey	15		40		70	
	15		40		70	
	20	17	30	37	55	65
H. W. Shalling ..	15		65		95	
	25		95		—*	
	30		80		—*	
	35	26	75	76	100	—
Average		27		57		—

* 100 per cent. not considered decidedly annoying.

servers found it possible to read the printing in the spot of regular reflection even with totally direct light. Naturally the observers check with themselves better than with each other. The basis of judgment would be somewhat different for each observer. On that account it was considered more important to have several observers rather than to repeat the observations a large number of times with the same observer.

Manifestly, these averages cannot be taken as the exact points at which given effects are obtained. They are merely an indication of the per cent. direct component which will produce the effects. As a matter of fact, if a large number of observations were made and an accurate average figure obtained for such a point as "perceptibly annoying," it would be of little more practical value than the above, since it would convey a different impression to different individuals depending on the difference in their bases of judgment.

It should be noted at this point that there are two distinct effects on the eye, of a spot of specular reflection on the work. First, if work is to be performed in the spot of specular reflection, there is a decrease in the ability to perform this work on account of the decrease in contrast between the printed or written characters and the blank portions of the paper. This is due to the fact that the printed characters will usually reflect specularly as much light as the paper itself and sometimes more.[1] The second effect is that of depression of visual function due to the presence of a bright spot close to the line of vision. The latter effect occurs, usually, when the work is performed outside of the area of regular reflection, but sometimes in the area if the light intensity from it is great. The figures given above refer to effects obtained in the spot itself, but it should not be overlooked that the spot is harmful even if it does not fall on the point at which work is performed. Either of these effects may be extremely serious, but their relative importance is unknown at the present time.

The figures indicate that on the average, with much of the paper in common use, regular reflection begins to be perceptible at 10 per cent. direct component of the illumination. This figure agrees

[1] M. Luckiesh, "An Analysis of Glare from Paper," *Electrical Review and Western Electrician*, June 1, 1912.

fairly well with the figure 12 per cent. which was determined as the approximate point at which the light unit has the same brilliancy as the ceiling under average conditions, and consequently the point at which direct light from the unit would cease to merge with light from the ceiling and would become visible as specular reflection from glazed papers. As the direct component increases beyond this point, the ease with which close visual work is performed diminishes. This is true, principally of work in which the position of the working surface is fixed. In other visual work, the worker will usually unconsciously assume a position such that glare from the work is least in evidence. This is difficult, however, unless the paper is backed by a board or cardboard, as the paper alone cannot be held perfectly flat and specular reflection is almost always in evidence from some part of it. A magazine as ordinarily held in reading, is perhaps the commonest example of this.

It is apparent, from these considerations, that, from the standpoint of glare from working surfaces, totally indirect lighting and semi-indirect lighting having a 10 per cent. direct component from each unit, are equally good. As the direct component increases, specular reflection from working surfaces increases. The only advantage of increasing the direct component beyond the point at which specular reflection due to direct light first appears is a small and practically negligible increase in efficiency. Considering that the efficiency of direct lighting is abandoned in order to obtain the advantages of a high indirect component of the illumination, it is the part of good engineering practise to see that the advantages are not lessened by too high a direct component. Probably 15 per cent. represents the most desirable high limit of direct component of the illumination, from the standpoint of glare from working surfaces.

The observations on shadows were made in the same room and with the same equipment as the observations on specular reflection from working surfaces. The same methods were used but observations were made at a point farther from the light-unit in order to obtain shadows of greater length. The observer was placed at a desk in such a position that the shadow from the

hand due to direct light fell directly across the work. Fig. 3 shows the position of the desk and light-unit. This was an unfavorable position with respect to shadows from direct light, but there was no noticeable shadow across the work with totally

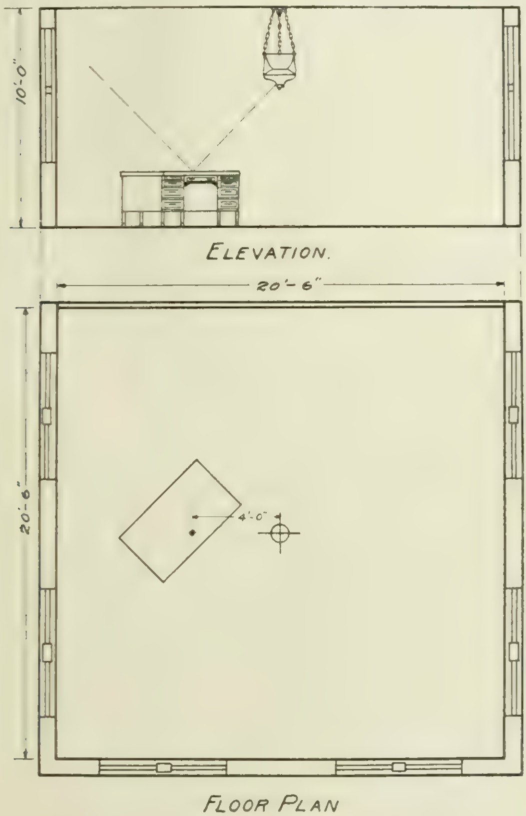


Fig. 3.—Relative positions of light-unit and desk in observations on shadows.

indirect lighting. The total illumination was kept at 3 foot-candles and this was consequently the intensity outside of the shadow at all times. Each observer was given the following instructions:

Observations are to be made while writing rapidly or following a printed page with a pencil, so that the shadow from the hand falls directly across the work.

State points at which the shadow is

Perceptible,

Perceptibly annoying,

(a) Due to the edge moving on the work,

(b) Due to depth,

Decidedly annoying,

Sufficient to prevent reading the printed submitted.

The printing submitted was the same as used in the observations on regular reflection. The last point was never reached. It was possible though difficult to read the print even with the indirect lamp turned off. It is apparent that some indirect light was then present, due to reflection from the floor to the ceiling and back to the plane of illumination. To determine the amount, readings were taken on the intensity of illumination in the shadow and it was found to be 0.038 foot-candles or 1.3 per cent. of the intensity outside of the shadow. No corrections were made for this as it is due to direct light and for our present purpose is better treated as part of the direct component. Table II shows the results of the observations.

TABLE II.

OBSERVATIONS ON SHADOWS ON WORKING SURFACES.

	Per cent. direct component of illumination at which shadow is							
	Perceptible		Perceptibly annoying due to Moving edge		Perceptibly annoying due to Depth		Ddcidedly annnoying	
Observer	Observation	Average	Observation	Average	Observation	Average	Observation	Average
W. J. Cady	10		25		45		75	
	10		30		40		70	
	10		30		45		70	
	5	9	30	29	55	46	75	72
W. A. Dorey....	5		25		35		50	
	5		25		30		70	
	10		20		25		45	
	10	8	20	22	25	29	50	54
H. W. Shalling..	10		20		45		85	
	10		25		50		90	
	5		35		55		85	
	5	8	30	28	55	51	90	88
Average		8		26		42		71

As stated these figures refer to the shadow due to the direct component only. This shadow differs from the shadow obtained from the indirect component, in that the former has a comparatively sharp edge. The shadow obtained from the indirect component usually has an indiscernible edge. Obviously there will be no annoyance due to the moving edge of shadows formed by the indirect component. Also the depth of such shadows will be less annoying since there will be no sharp contrasts in brightness on the work.

The observations seem to indicate that the figure 15 per cent. previously selected as the desirable high limit of direct component from the standpoint of shadow-elimination, is somewhat lower than necessary. However, some of the observers found a 20 per cent. direct shadow annoying at times. If annoyance is to be entirely avoided, it would seem that the direct component should be no higher than 20 per cent. and in some classes of work (such as close office-work and drafting) it should be lower.

Summing up the above considerations regarding all the advantages of diffusion due to a high indirect component of the illumination, *i.e.,* elimination of glare from working surfaces, elimination of objectionable shadows and reduction of the brilliancy of the light-unit, we may state with reasonable certainty that these advantages are obtained to the most desirable degree when the direct component of the illumination is 15 per cent. or less. If the direct component of the illumination is appreciably greater than 15 per cent., the advantages of the indirect component are apt to be seriously reduced. There is undoubtedly some value not far beyond 15 per cent. at which the advantages of a high indirect component are so seriously reduced, that the comparative inefficiency of this class of lighting is no longer justifiable on engineering grounds.

It should be noted than any conclusions drawn from the observations on specular reflection and shadows are more applicable to installations of one light-unit than to installations of more than one unit. In large installations, distant light-units will add, at any particular point, an illumination multi-directional in character. The effect would be the same as if the indirect component were increased without increasing the direct compo-

nent. In other words, the figures on direct component of the illumination apply to direct component from one unit only, regardless of the total illumination and the number of units in the installation. This indicates that a higher direct component of the flux from each light-unit may be allowed with installations of more than one unit than with installations of one unit only. Tending to counteract this effect is the cutting off of the light from distant units by interference of the body of the worker and other objects. This is of greater importance in indirect and semi-indirect lighting than in direct lighting since the average distance between light-units is greater; and this wider spacing is desirable since it effects a saving in the cost of installation. It should also be considered that while the effect of a single spot of light on the work, due to specular reflection, is reduced by using more than one unit, there are other spots added and some of these will fall on the work and within the range of vision. For light-units which are to meet the general demands of this class of service, it seems desirable on the whole to keep the direct component as low as one-unit installations require.

PHOTOMETRIC DISTRIBUTION OF THE INDIRECT COMPONENT.

The second part of the determination of the best distribution of light for indirect and semi-indirect lighting consists in determining the distribution of the indirect component of the light. The specification for this distribution must be based upon the degree to which the advantages of this class of lighting are obtained and the disadvantages avoided.

As stated above, all the advantages are due to the diffusion or multi-directional, character of the light. Obviously, this diffusion will be greater the wider the distribution of light on the ceiling, provided the angle with which light is incident on the ceiling does not make a difference in the character of the reflected light. It is necessary therefore to consider the character of reflected light from ceiling surfaces with various angles of incidence. Consider first, however, the disadvantages of a high indirect component. By far the greatest of these is low efficiency. There are also the minor disadvantages of bright walls and bright ceiling, but these should not be given great

weight, as they are relatively unimportant. The remedy for too much light on the walls is to use dark-colored walls even though this means a slight reduction in efficiency. From the standpoint of brightness of ceiling, it is desirable to have a wide distribution of light, thus giving a low ceiling brilliancy and eliminating to a large degree the spotted effect which is obtained if a large portion of the light is concentrated directly above the unit.

It is evident, that, subject to revision with a greater knowledge of the character of ceiling reflection and its effect on efficiency, the distribution of light on the ceiling should be as wide as possible. In order to obtain more definite data on these points, two investigations were made, one on the character of reflection obtained from ceilings ordinarily used and the other on the efficiency-values of various light distributions on the ceiling.

CHARACTER OF CEILING REFLECTION.

The ceilings most commonly met with in rooms in which indirect or semi-indirect lighting would be used are of plaster with a finish of calcimine, muresco or some similar paint. Papered ceilings and painted metal ceilings are occasionally met with. This investigation was conducted on two surfaces both of plaster with a calcimine finish. The tests were made on disks ten inches (25.4 cm.) in diameter. These were finished by an interior decorator, who was instructed to give one the roughest finish and the other the smoothest finish of this character which would be found in practise. The rough surface was practically the extreme in that direction. The smooth surface could not be called extreme as there was no glaze to the surface such as is found on a metal ceiling painted with oil paint or a ceiling papered with a glazed paper. These two conditions are not common, however. Most papers used for ceilings have practically the same degree of diffusion as the smoother surface investigated.

In order to determine what degree of diffusion was obtained from the two surfaces investigated, special photometric apparatus was devised. Fig. 4 is a photograph of this apparatus. It consists of an attachment to the ordinary universal rotator of a photometer. The attachment comprises an upright support, and a horizontal arm holding a lamp and reflector at the end. The re-

flector projects a beam of light on the test disk, which is supported on the rotator in exactly the position which a light-source would occupy when being tested. A lamp approaching a point source and a reflector of parabolic contour are used, so that the reflected rays are practically parallel. The reflector is 3.86 feet (1.177 m.) from the disk. The arm can be turned in any direction in a vertical or horizontal plane without changing the setting of the universal rotator. The disk can, therefore, be rotated independent of the movements of the arm. It is evident that by movements of the arm in the horizontal plane any angle of incidence of light upon the disk can be obtained. Then by

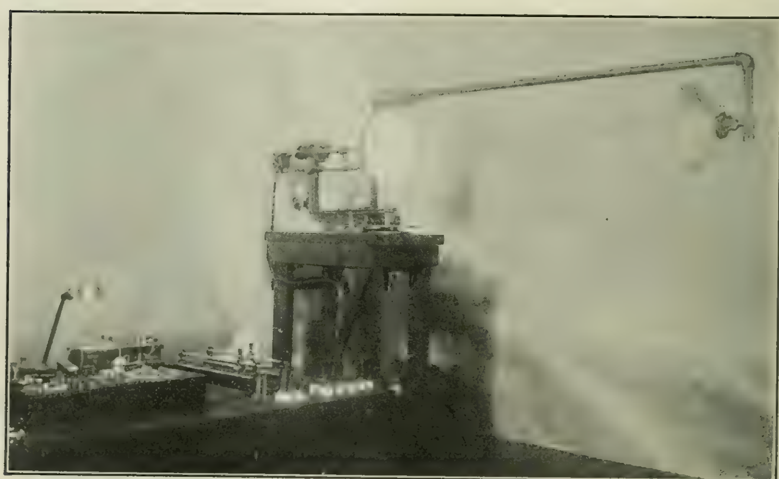


Fig. 4.—Apparatus for testing diffusion and co-efficient of reflection.

the ordinary movement of the universal rotator in a horizontal plane photometric readings of the light reflected from the disk can be made with the disk rotating. Such tests would give distribution curves of the reflected light in the plane of the angle of incidence with varying angles of incidence. These tests would show very fully the extent of diffusion obtained from the reflecting surface. However, in order to make a correct determination of the coefficient of reflection of the surface, it is necessary to make tests in other planes than those containing the angle of incident light. To make such tests the arm is moved in

a vertical plane until the angle of incidence is that desired. The rotator is then set at the various angles in a horizontal plane and readings taken on the rotating disk. In this way it is possible to obtain sufficient tests to determine the complete hemispherical

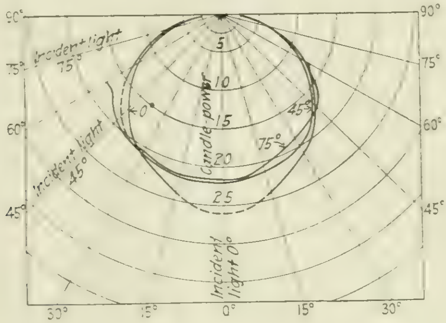


Fig. 5.—Distribution of light from rough white calcimine ceiling surface. Tests made in plane perpendicular to surface and containing the incident ray. 100 lumens incident. (Dotted portions of curves interpolated).

distribution of the light from the disk with any desired angle of incidence.

Figs. 5 and 6 show the photometric curves obtained from the rough and smooth ceiling surfaces respectively, in the plane of

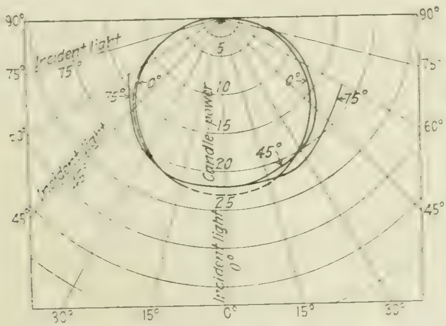


Fig 6.—Distribution of light from smooth white calcimine ceiling surface. Tests made in plane perpendicular to surface and containing the incident ray. 100 lumens incident. (Dotted portions of curves interpolated).

the angle of incidence, the light being incident at various angles as stated on the curves. The curves for three angles of incidence only, are shown as the addition of others would confuse the figure. They are all similar, however. It will be seen that the

photometric curves of these surfaces approach remarkably closely the curve of perfect diffusion, which is a circle, tangent to the surface. They are so nearly the same that for practical purposes we can assume that all ceilings ordinarily met with are perfectly diffuse reflectors of light. Tests were made in planes other than the plane of incident light, but these tests are not shown as they give approximately the same character of distribution as the tests in the plane of the angle of incidence. They make possible the determination of the absolute co-efficients of reflection. These are given in table III. Zero degree angle of incidence means incident light normal to the surface. With 90 deg. incidence the light would be grazing the surface.

TABLE III.

REFLECTION COEFFICIENT OF WHITE CALCIMINE CEILINGS.

Angle of incident light Deg.	Coefficient of reflection	
	Rough surface Per cent.	Smooth surface Per cent.
0	78	74
15	76	75
30	77	75
45	76	73
60	77	76
75	75	76
Average	76.5	74.8

These results show that we can expect approximately the same distribution and efficiency of reflected light from any point on the ceiling no matter what the angle of incidence. The extent of diffusion obtained, and therefore, the degree to which the advantages of a high indirect component are obtained will, in the light of the above results, be better, the wider the distribution on the ceiling. This distribution should therefore be as wide as efficiency considerations will permit.

THE EFFECTS OF LIGHT-DISTRIBUTION ON EFFICIENCY.

In order to determine the effect of light distribution on efficiency another series of tests was made. A light-unit of known photometric curve was suspended from the ceiling, and the ceiling area above the unit divided into circular zones, so that the zones included respectively light from the unit in the solid angles 170 deg. to 180 deg., 160 deg. to 170 deg., 150 deg. to 160 deg., etc., angles being measured from the vertically

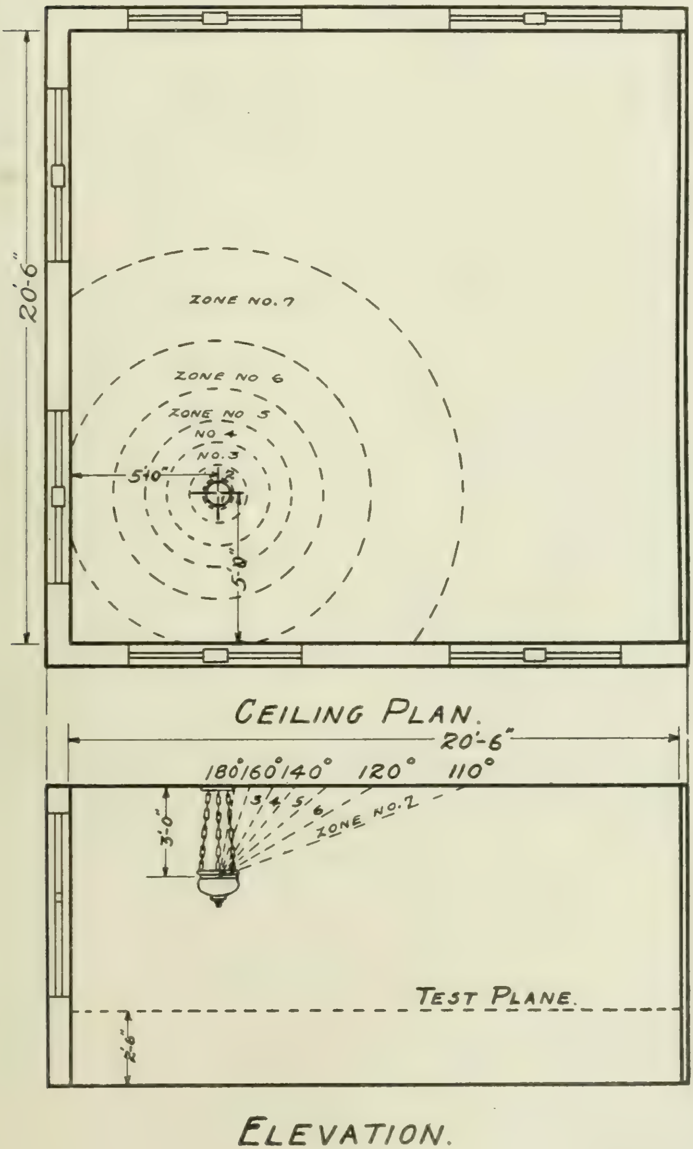


Fig. 7.—Test room showing positions of ceiling zones and light unit.

downward direction. This makes the zenith 180 degrees. The ceiling was white and partially covered with black cloth leaving one zone at a time reflecting light into the lower portion of the room. The flux of light incident on each ceiling zone was determined from the photometric curve of the light-unit. By means of illumination tests the quantity of light reflected from each zone was determined. The comparison of these two gives a value for the reflecting efficiency of the zone.

The room used for the tests was 20 feet, 6 inches (6.16 m.) square and 10 feet, 0 inches (3.048 m.) in height—the same

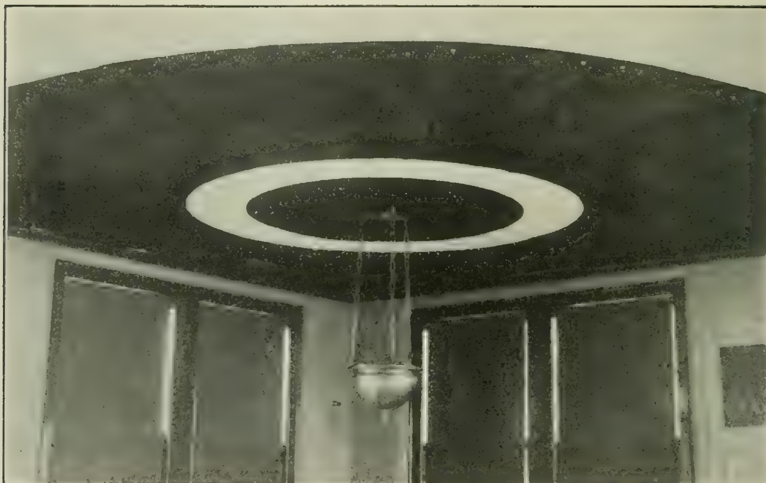


Fig. 8.—Ceiling zones and light-unit. Zone No. 5 white.

room as used for the observations on regular reflection and shadows. The ceiling was white calcimine rough finish, the same as the rough surface used in the diffusion tests. Fig. 7 is a ceiling plan and elevation of the room, showing the position of the light-unit and the arrangement of zones on the ceiling. Fig. 8 is a photograph of the ceiling partially covered with these black circular zones. When the photograph was taken zone No. 5 was white.

The cloth used was black Canton flannel. It was mounted on pasteboard to facilitate attaching to the ceiling. The nap of each piece was brushed up before attaching to the ceiling so

that much the same effect as black velvet was obtained. A test by the Bureau of Standards on cloth of this character indicates a co-efficient of reflection slightly less than 2 per cent. The shades over the windows were dark green and were pulled down during these tests. The light-unit was a totally indirect unit using a mirrored reflector and 250 watt tungsten-filament lamp. This unit is shown in fig. 8. Fig. 9 shows its photometric curve. In making this photometric test the complete fixture was used

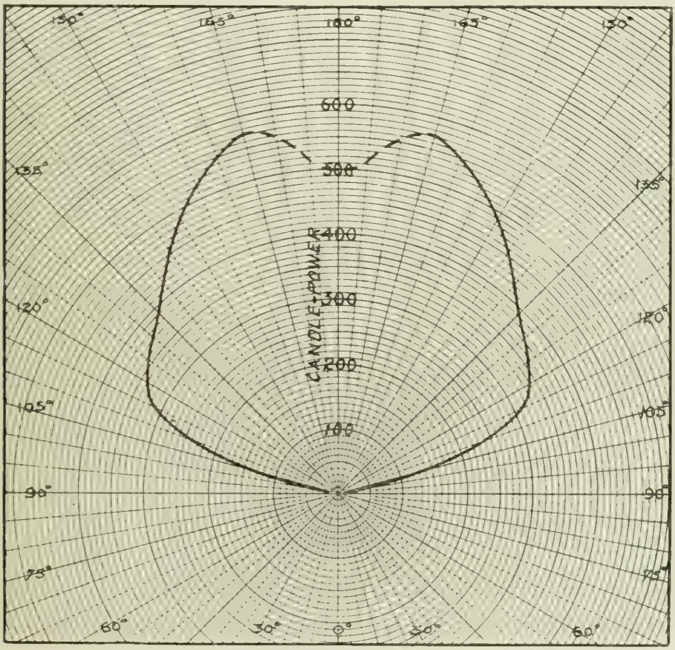


Fig. 9.—Photometric curve of light-unit used in tests of ceiling zones. (Dotted portions of curve interpolated).

and the supporting apparatus necessary, interfered with the light emitted above 165 deg. The readings above that angle were therefore lower than they should have been and the curve was interpolated using values which tests on similar reflectors indicate probable. The unit was hung with center of lamp filament 3 feet (0.914 m.) from the ceiling. It was suspended near one corner of the room 5 feet (1.52 m.) out from each of the two walls. This position was selected as including on the

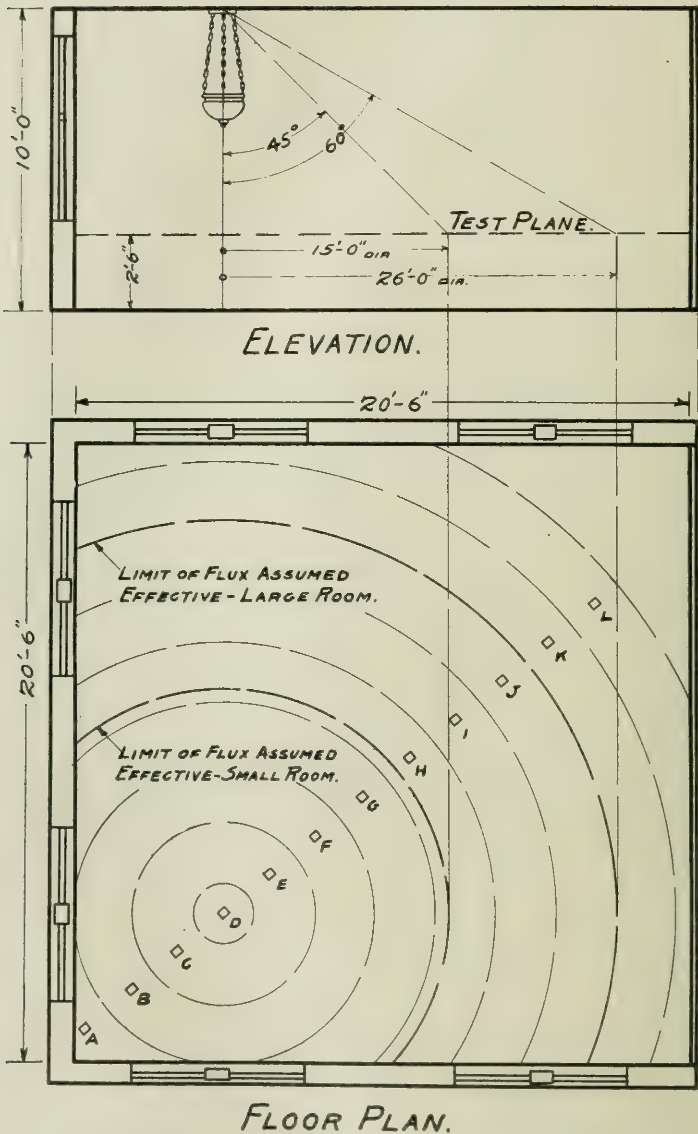


Fig. 10.—Test-room, showing stations (indicated by small squares) and areas of flux assumed useful.

ceiling practically all of the light from directly above out to 120 deg. from the nadir or 60 deg. from the zenith. The position made it possible to take illuminometer readings at points farther distant from the light-unit and with less wall effect than would have been possible had the unit been placed in the center of the room. Illumination readings were made on a horizontal plane 2 feet, 6 inches above the floor. The plan given in fig. 10 shows the stations at which readings were made. The first test was made with all seven zones black. The black area then included all of the light from the zenith out to 110 deg. Practically the only illumination received was from light reflected from the ceiling after being emitted from the unit at angles between 90 deg. and 110 deg. Then the cloth over zone No. 7 including light between 110 deg. and 120 deg. was removed and another test made. The cloth over zone No. 6 including light between 120 deg. and 130 deg. was then removed and the cloth for No. 7 replaced on the ceiling. Similarly in turn No. 5 was removed and No. 6 replaced, No. 4 removed and No. 5 replaced, etc. Each test with a zone white gives the illumination obtained from that zone plus the illumination obtained in the first test with all seven zones covered. Thus by subtracting the first test from each of the others, the illumination obtained from each zone was determined. From the photometric curve the number of lumens incident on each zone of the ceiling was determined. From the illumination readings the useful lumens obtained in any portion of the plane of illumination can be determined by multiplying the readings by the proper areas. For comparison of the value of the various ceiling zones, circular areas on the plane of illumination 15 feet (4.57 m.) and 26 feet (7.92 m.) in diameter were selected. The former subtends a solid conical angle of 90 deg. (45 deg. each side of the nadir) from a point on the ceiling directly above the light-unit. The latter subtends a solid angle of 120 deg. (60 deg. each side of the nadir) from the same point. These were selected as representing roughly the portions of the plane of illumination which would receive useful light in a small room and a large room respectively. The first condition represents approximately what would be obtained in a room 13 feet, 6 inches (3.11 m.) square with a ceiling 10 feet (3.048 m.) high and one light-unit in the center. The

second condition assumes that in a large room 10 feet (3.048 m.) high light received on the plane of illumination out to 13 feet (3.96 m.) from the unit is useful on the average. The values thus obtained do not represent accurately the useful light in a small room and a large room respectively, but they give a fair basis for the comparison of efficiency of the various zones on the ceiling. Fig. 10 shows the areas selected and shows the stations on the plane of illumination. These stations were two feet (0.609 m.) apart. The reading at station D was considered the average illumination over a circle directly under the unit and two feet in diameter. The reading at E was considered the average illumination of a ring having an inside radius of 1 foot (0.304 m.) and an outside radius of 3 feet (0.914 m.). The

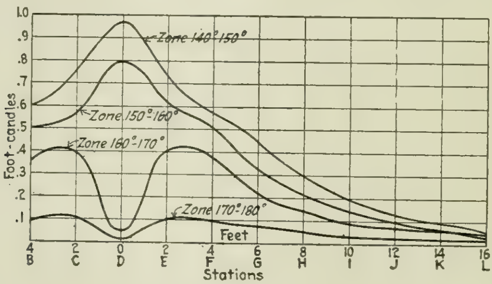


Fig. 11.—Illumination curves obtained from ceiling zones 1, 2, 3, and 4, showing foot-candles as measured.

reading at F was considered the average illumination of a ring having an inside radius of 3 feet (0.914 m.) and an outside radius of 5 feet (1.524 m.). Similarly, for other stations. These rings are shown in fig. 10. In obtaining lumens from the foot-candle readings, the readings at stations A, B and C were neglected, since wall reflection affects these stations more than the others. Readings were taken at A, B and C merely to obtain an indication of the effect of wall reflection on these tests. Figs. 11 and 12 show the illumination curves obtained. These curves are shown as actually measured rather than reduced to the same incident flux, since if shown the latter way they would come so close together as to be confusing. Table IV, however, gives the lumens incident on each zone as well as the comparative efficiencies of the zones, on the two bases of comparison selected.

The curves show plainly the effect of interference of the light-unit with light reflected from the ceiling. With the zone 170-180 deg. the low part of the curve is naturally directly under the light-unit. For the zone 160-170 deg., there is also a dip directly under the unit. For the zone 150-160 deg. this dip has moved out about 2 feet (0.609 m.) from the unit. For 140-150 deg. the dip is less noticeable and farther from the unit. For 130-

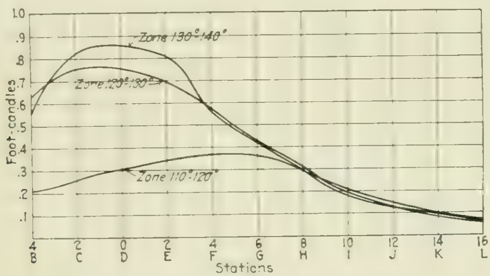


Fig. 12.—Illumination curves obtained from ceiling zones 5, 6, and 7, showing foot-candles as measured.

140 deg. it is still farther out and for the next zone it has ceased to show in the curve.

TABLE IV.

RESULTS OF TESTS ON CEILING ZONES.

Ceiling zone No.	Angle from light-unit, including zone Deg.	Lumens incident in zone	Effective lumens		Effective percentage of flux striking ceiling zone.	
			Small rooms	Large rooms	Small rooms	Large rooms
1	170–180	49.0*	12.6	24.6	26*	50*
2	160–170	162.0	50.2	81.2	31	50
3	150–160	241.0	73.3	123.0	30	51
4	140–150	285.0	89.6	155.0	31	54
5	130–140	303.0	89.0	151.0	29	50
6	120–130	319.0	87.8	154.0	28	48
7	110–120	309.0	63.1	134.0	20	43

* Values obtained by interpolating photometric curve.

It will be noted that there are a number of sources of possibly inaccuracy in these tests. In the first place, the photometric curve of the light-unit was made at a distance of 10 feet, while it was used for figuring flux in ceiling zones at distances varying from 3 to 8 feet (0.914 to 2.438 m.). This should not introduce serious inaccuracy, however, since the light-unit is

comparatively small (about 12 inches is the diameter of the reflector) and the distribution is far from concentrating. Photometric tests which have been made on an intensive type reflector at distance of 4, 6, and 8 and 10 feet (1.219, 1.828, 2.438 and 3.048 m.) show very little difference in candle-power or distribution results. Another element of possible inaccuracy is wall reflection; it is believed, however, that this does not enter to a great degree as the walls average a fairly dark color. The readings at A, B and C are not much higher than the readings at G, F and E, which are at corresponding distances from the light-unit. If wall reflections were serious A, B and C would show much higher values than G, F and E. Furthermore, the subtraction of the first test, with all seven zones black, from the others largely eliminates wall reflection from the results. A third source of possible inaccuracy is the fact that some of the zones are incomplete. This has no effect, however, upon zones Nos. 1 to 6 inclusive. It possibly renders of less value the figure obtained for zone No. 7. The curve for zone No. 7 shows lower readings on the side of the missing portion. Owing to the diffuse character of the reflection from the ceiling there should be no inaccuracy due to the fact that stations are in a straight line and not distributed over the room as centers of equal squares.

The results show that the zones from the light-unit gradually increase in value from the zenith down to 140 deg. The zone 140 deg. to 150 deg. is the most efficient, but those on either side are not by any means inefficient. At 120 deg. the efficiency has dropped off considerably. From 150 deg. to 180 deg. the efficiency decreases slowly, but the ceiling is comparatively efficient directly above the unit. These effects hold for small rooms and large rooms in nearly the same degree. The figures will vary somewhat with the size and drop of the light-unit, since the interference by the unit with light reflected from the ceiling will vary with these factors. Conditions tested are believed to represent average conditions.

To obtain the highest efficiency the light from the unit should be included in the zone 140 deg. to 150 deg. Good diffusion and appearance will be obtained if the illumination on the ceiling is practically uniform from 180 deg. out to 140 deg. and drops off

gradually beyond that. Efficiency considerations will permit this.

Below approximately 105 deg. the light is likely to strike the walls, and the candle-power should therefore be low. Below the horizontal, it is reasonable to assume that the direct component will not include light much above 60 deg. from the vertically downward direction. The candle-power between 60 deg. and 90 deg. should be low both to keep light from the walls and to protect the eyes from the light-unit itself. For good appearance of the unit there should be some light in this zone, however.

PROTOTYPE CURVE.

On the basis of the considerations which have been brought out regarding the most desirable per cent. direct component and

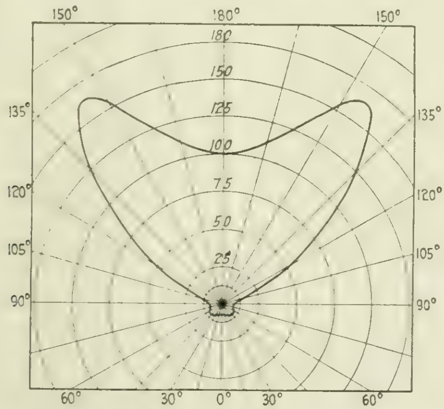


Fig. 13.—Prototype curve for semi-indirect lighting. Scale 100 units directly upward.

the most desirable distribution of light, a prototype photometric curve has been drawn up. This is shown in fig. 13. If the foregoing treatment of the subject is correct, this photometric curve is the most desirable curve for semi-indirect lighting. For totally indirect lighting, the most desirable curve would include only the portion above the horizontal, and the candle-power would decrease to zero at approximately 105 deg.

The distribution in the upper hemisphere is such that the illumination on the ceiling is uniform out to 30 deg. from the

zenith or 150 deg. from the nadir. The maximum flux is in the zone 140 deg. to 150 deg. and the maximum candle-power at 145 deg.

In obtaining the relative proportions of direct and indirect flux emitted by the light-unit, it was necessary to consider the efficiency with which the indirect flux is utilized. It was found by a study of illumination tests available on direct and semi-indirect lighting that in rooms with white or light-colored ceiling and medium to light walls, 30 per cent. to 50 per cent. of the indirect flux reaches the horizontal plane of illumination. Forty per cent. may be taken as an average figure, sufficiently accurate for our purposes. It was found also that in small rooms, where one to four units would be used (in this class of lighting), the flux from the light-unit, used directly, is included in the zone 0 deg. to 60 deg. from the nadir, approximately. This would indicate that, on the average, the flux included between 60 deg. and 180 deg. is 40 per cent. as useful in producing illumination as the flux 0 deg. to 60 deg. The most desirable direct component of the illumination was found above to be 15 per cent. Therefore, for small rooms, the most desirable direct component of the flux emitted by the unit is 0.40 $\times$ 0.15 or 6 per cent. This assumes that the proportions of direct and indirect illumination at any point will be in the same proportion as the total useful direct and indirect flux; in other words, that the distribution of illumination obtained from the direct component is the same as that obtained from the indirect component. This is not strictly true, the direct component of the illumination is usually greater proportionally than the indirect at points nearly under the unit. This would call for a direct component of the flux lower than 6 per cent. if the results desired are to be obtained at points near the light-unit. On the other hand, as stated before, in rooms where more than one unit is used, there is the counteracting effect of light from distant units and this tends to increase the indirect illumination at any point more than the direct. On the whole, it may be stated that 6 per cent. is a desirable direct component of the flux for small rooms, while for large rooms a higher component will give as good results, although little is to be gained by the use of a higher component. The prototype curve is figured

on the basis of 6 per cent. of the total flux of the unit in the zone 0 deg. to 60 deg.

Some variation from the prototype curve is permissible with little sacrifice in the degree to which the advantages of this class of lighting are obtained. Above the horizontal it would not be serious to have the distribution of light vary considerably. A concentrating curve, however, would decrease to a marked extent the degree of diffusion obtained and, therefore, the degree to which specular reflection from the working surfaces and sharp and deep shadows are eliminated. A concentrating distribution would also present a brighter and smaller spot on the ceiling with the attendant disadvantages of poorer appearance and less comfort to the eyes. Below the horizontal the distribution of light is comparatively unimportant, but extreme distributions are undesirable. The most serious results of a departure from the prototype curve would result, if the proportions of the light above and below 60 deg. from the nadir, were changed to a marked degree. A decrease in the per cent. below 60 deg. would not be serious. An increase in the per cent. below 60 deg. would decrease the value of the diffusion obtained from the indirect component. It would require but little increase beyond 6 per cent. of the total flux to introduce a direct component of the illumination great enough to produce specular reflection and objectionable shadows. It is probable that if this flux is increased to as high a value as 10 per cent. (giving a direct component of the illumination of 25 per cent.) the value of the diffusion obtained from the direct component would be seriously impaired. In that case it would undoubtedly be better from the engineering standpoint to have a well-designed direct lighting system.

CONCLUSION.

The engineering advantages of semi-indirect lighting are obtained to their fullest degree and most efficiently if the prototype photometric curve here given is approximated. This curve is based on the following considerations.

(a) The flux below 60 deg. from the nadir is 6 per cent. of the total flux.

(b) The candle-power values between 60 deg. and 105 deg. are low.

(c) Above 105 deg. the candle-power increases to a maximum at 145 deg. and provides for approximately uniform ceiling illumination between 145 deg. and 180 deg.

Variations of a considerable degree from the prototype curve are serious with reference to the proportion of the light below 60 deg., undesirable in the distribution of light above the horizontal, and comparatively unimportant in the distribution of light below the horizontal.

The author desires to express his appreciation of laboratory facilities kindly placed at his disposal by the Nelite Works of the General Electric Company, also of valuable assistance rendered by Messrs. H. L. Jenkins, W. J. Cady, W. A. Dorey, H. W. Shalling and A. J. Sweet.

DISCUSSION.

DR. H. E. IVES: The other morning in the discussion of Dr. Hyde's paper on "Research Methods" I tried to make some specific suggestions, thinking it might help in the comprehension of some of the propositions in the paper. I have been gratified by noting that most of the criticisms of the present paper could have been taken care of by the suggestions which I made as to the method which should be pursued in writing up a research. My first proposition was that the author should make an exact analysis of his problem. The criticism of the first part of Mr. Rolph's paper simply comes down to disagreement with his analysis. Specular reflection is not conditioned by relative direct and indirect *illumination,* but by the relative *intrinsic brightness* of the light source and surroundings. Next, the assumptions have not been carried to the end in parallel columns. Instead of mentioning the restricted conditions which hold in the experiments, numerous points have been left out in drawing conclusions, and these consequently appear to be general. They have been continued on that basis, and not as results of a definite experiment.

MR. L. B. MARKS: I subscribe to the statement of our president that we have in this paper a presentation of a number of facts of great importance to practising illuminating engineers.

The tests described by Mr. Rolph were made in a room about 20 feet (6.096 m.) square and 10 feet (3.048 m.) high; the ceiling of the room was light and the walls dark in color; a very large percentage of the wall space (perhaps 50 per cent.) was broken by windows. Three sides of the room had two windows each, and the fourth side consisted of a wooden partition, dark in color. The light unit was suspended from the ceiling at a height of about 6½ feet (1.98 m.) above the floor (to bottom of globe).

I take it that each of the premises set forth in the paper has a bearing upon the conclusions reached. On the second page we find the statement that the walls should be dark in color. There is, no doubt, some question as to whether this is true or not. From my own practise I am inclined to believe that there is an advantage in having dark walls under certain conditions and light walls under other conditions. When the working intensities are high, dark walls may be very objectionable. This fact is borne out by the results of Dr. Cobb's tests[1] described yesterday, in which it was shown that vision is actually improved by filling the visual field with a surface almost as bright as the object viewed.

Again, on the same page, we find the statement "A highly diffused character to the illumination tends to eliminate specular or regular reflection from the surfaces worked on." Generally speaking this is, of course, true, but there are instances in which it is not true. We find, for example, that the indirect system of lighting sometimes gives us the very worst conditions of glare it is possible to get, and yet the light is thoroughly diffused. The reason is simple enough; take the case of a big drafting room, rectangular in shape, say 50 feet (15.24 m.) wide and 60 feet (18.288 m.) long and 10 feet (3.048 m.) high; you light the room by indirect lighting, the ceiling being brightly illuminated throughout. There will not be a draftsman in the room who can work without the worst kind of glare from the polished surface of the tracing cloth.

In considering the conclusion reached in this paper, it is highly desirable to consider all of the premises and their bearing on the tests. This leads one to consider another statement on the

[1] P. W. COBB, "Vision as Influenced by the Brightness of Surroundings," TRANS. I. E. S., Dec., 1912.

third page. "Any uni-directional light will cause specular reflection." This is broadly true, but if the specular reflection does not reach the eye of the observer, a uni-directional or lateral light may be advantageous. I have said that the worst cases of specular reflection may occur in indirect lighting. We can cure the trouble to a large extent by having proper direction of the light. If we had the light sources located on either side of the drafting room previously described, giving us lateral lighting, the draftsman facing the length of the room and the tables arranged at right angles to the side walls, no draftsman would directly face a line of light, especially if the tables were located a short distance away from the walls. You would thus eliminate glare to a very large extent, and have a better arrangement than you could get even in the day time, unless you had windows on both sides. This fact is so patent that it seems desirable to call attention to it in connection with the results found in the paper.

Referring to the fifth page—if the light unit is arranged and mounted as shown in fig. 1, the walls get very little or no light. The author seems to have intentionally selected a room in which the diffusion of light is accomplished almost entirely by the ceiling and not by the side walls.

It is a fact that with the direct lighting system installed to the best advantage, we depend to a large extent for diffusion, not only upon the ceiling but upon the walls. If the walls are dark, as in the tests described in the paper, the advantage of a larger direct component is minimized; but if, on the other hand, the walls are light, then we change the premises of this paper. How much difference this would make in the actual ratios found in these tests, I do not know, but I have no doubt that the difference would be considerable.

It seems to me that in planning his lighting installation, the author underestimated the value of the very important feature of lateral lighting by reflection from the side walls. It is perfectly clear that if the illumination came from the sides as well as from above, the shadow effects would be very different than those upon which the results of tests described in the paper are based. I ask the author whether he would not have obtained

substantially different results in the tests by changing the conditions, as follows:

(a) Light (unbroken) walls instead of dark colored walls.

(b) Change in the height of the lighting unit.

(c) Increase in the visible area of the direct lighting unit.

(d) Change in the specific brightness of the direct lighting unit.

(e) Change in the intensity of illumination at which the tests were made.

Changing the height of the unit would, of course, vary the angle of the direct light.

Increasing the visible area of the direct lighting unit would, of course, modify the shadows produced by the light. This applies to the shadow tests in fig. 3 and table 2. It seems clear that generally speaking, if you have a lighting source of much larger area, you reduce the glare from the specular reflection. If you have two large globes, you may reduce it still further, and so on. Hence the general conclusion arrived at in the paper does not appear to hold, except for the specific conditions of the test reported.

Carrying to the extreme the illustration which I just made, suppose we increased the area of our semi-indirect lighting unit until it was equal to the area of the ceiling. We would then have the equivalent of a ceiling glazed with opal glass and we would have a semi-indirect lighting system converted into a direct lighting system that could be made to give substantially the same results in diffusion as the indirect. Obviously the ratios given in the paper would not apply.

In regard to the specific brightness of the lighting sources, it seems clear that this factor would have to be taken into consideration in connection with the ratios cited in the paper.

Mr. M. Luckiesh: Mr. Marks has called attention to several points in Mr. Rolph's paper which are open to criticism. One of these questions I wish to more fully discuss.

Mr. Rolph concludes in the first part of his paper that a 15 per cent. direct component of illumination is the maximum which can be used in order to have no glare from reflecting surfaces. It is unfortunate that Mr. Rolph did not state that this is a

conclusion pertinent only to the conditions of the test, and especially does it hold only for the fixture used.

The glaring spot on a reflecting surface, such as paper, is due to the specular reflection of the surface. In other words, the bright spot on the paper is the reflected image of the light unit. To illustrate the defect in Mr. Rolph's unqualified conclusion, suppose that the 15 per cent. direct component came from a light source of one square inch area. Would not the glaring effect or the brightest spot on the paper be much brighter than if the area of the source of direct light was 100 square inches (0.0645 sq. m.) in area? In the first case the intrinsic brilliancy of the source of the direct component would be, perhaps, one hundred times the brightness of the latter. Of course I am assuming the same illumination on the paper in both cases. The specification of the amount of direct light possible with absence of glare from the paper cannot be expressed correctly in terms of percentage of the total illumination. It can, however, be better expressed, if at all, in terms of intrinsic brilliancy of the source of direct light. However, I do not believe that this factor can be expressed in a simple ratio for the general case, and I believe that Mr. Rolph should specifically state that his figure of 15 per cent. holds only for the conditions of the test and especially for the light unit which was used.

The height of the light unit will also affect his results.

There are several other points which I would like to add, but my observations have already been published in the paper referred to in Mr. Rodph's paper. I do not depreciate the practical value of this paper however.

MR. J. R. CRAVATH: Before commenting upon Mr. Rolph's paper, I would like to say that perhaps many of Mr. Marks' questions will be found to be answered in the paper upon a more careful perusal.

As to the work done by Mr. Rolph, I want to express my hearty appreciation. As you know, I have been investigating along these lines for a number of years past and Mr. Rolph's conclusions correspond very closely with those which I have been able to reach so far. I think Mr. Rolph's paper must be read very carefully and due consideration be given to all of the modi-

fications which he states. Like Mr. Marks, I would question the statement on the second page, that the walls should be dark in color if the highest visual efficiency is to be obtained. I think this has yet to be proved. Dr. Cobb's paper* indicates otherwise.

I would also question the statement regarding the usefulness of the small direct component as an aid to perspective. I doubt if the small amount of light added aids in any way to the seeing of perspective.

It should be borne in mind that Mr. Rolph's statement that 15 per cent. is a desirable amount of direct component indicates his conclusions as to the limit rather than the desirable fixed amount. He has investigated by various methods and concludes that the direct component should not be over 15 per cent.; it could be less without doing any damage, as far as engineering considerations are concerned. If it is less, it is largely a matter of artistic effect, which we are not, at present, considering.

I think the artistic effect is enhanced by a 15 per cent. direct component. Aside from that the only advantage in having it as high as 15 per cent. would be the supposedly higher efficiency. At the present time I do not think there is any apparatus on the market which enables us to get a higher efficiency with 15 per cent. direct component than we could get with a properly designed purely indirect system, though this may be possible.

As to the form of the curve which Mr. Rolph suggests as ideal, I think when we get into practise it can be well modified in the direction of the curve which he shows on the twenty-first page of his paper, for the following reasons: in the first place, the curve which he suggests might, in some cases, produce a rather unpleasant effect on the ceiling because of the sharp cut-off; that is, the quick transition from high to low illumination. It would also, in many cases, result in too much sacrifice for the sake of diffusion by reflecting so much of the light to the ceiling near the walls.

Mr. Rolph says that we want to get the ceiling uniformly illuminated for the best effect, but we have to make some compromises sometimes between good illumination and the best effi-

* P. W. COBB, "Vision as Influenced by the Brightness of Surroundings," TRANS., . E. S., Dec., 1912.

ciency. Such a curve might also produce non-uniformity in cases where a number of units were used.

I want to dissent very much from the idea that specular reflection is due entirely to high intrinsic brilliancy. Mr. Jordan is right; it is a matter of contrast between the brilliancy of the light source and its surroundings. In other words, the matter of contrast coming in there covers the whole thing.

Mr. Ward Harrison (Communicated): From the data presented in this paper it appears that the author commends direct illumination as being the most economical, and semi-indirect, with a direct cmponent not to exceed 15 per cent., as being the most desirable. On the thirteenth page he states that "There is undoubtedly some value not far beyond 15 per cent. at which the advantages of a high indirect component are so seriously reduced that the comparative inefficiency of this class of lighting is no longer justifiable on engineering grounds." In other words he claims that there can be no compromise. It seems that Mr. Rolph's generalization would be better sustained if in the same paragraph he qualified it with the statement that it applied only to those few cases in which the 15 per cent. or greater direct component must necessarily be incident on the plane at the worst possible angle.

On the second page of the paper it is stated that two important requirements of good illumination, namely, absence of specular reflection in the direction of the eye, and of sharp and deep shadows, can often be fairly well met by a properly designed system of direct lighting. Now instead of designing the test system, as in fig. 6, so that the direct component would at best be of no value, suppose that a well planned direct system were installed; while the latter system, according to Mr. Rolph, would be somewhat inferior to indirect lighting, it is nevertheless capable of yielding fairly satisfactory results. For the room described in this paper, such a direct system would perhaps consist of a distributed layout of four or more units. Suppose that having made this installation and having obtained a reasonable measure of satisfaction, we considerably increased the indirect component by simply inverting the units, accompanying this change if necessary with the substitution of a somewhat larger

size of lamp. Then as the relative amount of indirect light is increased, might not the system become more satisfactory? There is nothing in Mr. Rolph's paper to disprove this idea and in the absence of conclusive data I am inclined to the opinion that it would.

If, as Mr. Rolph's investigation would lead us to believe, indirect illumination is most desirable, then a combination of indirect and direct lighting involves a compromise; but, so does almost all engineering practise involve a compromise between desirability and cost. There are many users of light who do not desire, nor feel they can afford, indirect illumination, but who are nevertheless willing to pay for something a little superior to the ordinary direct systems. To my mind Mr. Rolph's paper suggests the conclusion that these consumers may secure the greatest possible return from their expenditure by installing a semi-indirect system, having a component of direct light possibly as high as 50 per cent.; an installation so designed that it may represent the very best practise in direct, as well as indirect illumination.

Mr. H. T. Spaulding: The figures given in this paper are undoubtedly of value in the consideration of the case in hand, namely, ideal conditions in semi-indirect lighting. It seems to me, however, that the matter of efficiency should be given more consideration. An installation of this type will be less efficient than a straight indirect system inasmuch as the direct component is very small and a less efficient reflector is used for the indirect component. The advantages of semi-indirect illumination over indirect illumination are efficiency and perhaps appearance. If we, therefore, reduce the efficiency, the system loses a great part of its value. If we increase the direct component above the figure given in the paper serious results as far as glare and presence of shadows are concerned should not be obtained and the efficiency will be increased so that the system is practicable for ordinary use.

The paper does not deal with the relative efficiencies of various classes of lighting, but some results of a recent test may be of interest here. The test was conducted in a room approximately 20 feet x 40 feet (6.096 m. x 12.192 m.) equipped with eight

lighting units such that the wattage was approximately 1.5 watts per square foot. The ceiling was white and the walls were such as are to be found in the average office, so that the results should be fairly close to average. Tests were made with direct lighting with prismatic glass reflectors, semi-indirect lighting with translucent dishes and totally indirect units. The results were as follows:

Effective lumens per watt—direct lighting	3.52
" " " " semi-indirect lighting	2.77
" " " " indirect "	1.74

On the basis of the direct lighting the actual lumens per watt efficiency for the semi-indirect and the totally indirect would be approximately three-quarters and one-half, respectively.

Mr. S. G. Hibben: I want to bring up the question of shadow, which I do not think Mr. Rolph has fully covered. In the first place, from engineering considerations it is not quite right to make tests in an office room and say that the results apply equally well to a drafting room, machine shop, or residence; in other words, the shadows seemingly found objectionable in the test room might easily be all right in the drafting room, or vice versa. I can best illustrate this idea by mentioning that in engraving or in any work with fine tools, it is very hard to know how far the point of the tool is from the work unless you have a slight shadow upon the work. When the shadow and the point of the tool or pencil converge, you can readily locate that working point.

From an artistic or esthetic viewpoint, shadow must at least be given some consideration, although Mr. Rolph has stated on the second page that esthetic advantages would not be considered here. It is not fair not to consider them, if general principles are going to be laid down.

Mr. Rolph also states on the same page that "a small direct component also aids in giving perspective." It is hardly fair to state that a small direct component will aid perspective without noting that a larger direct component will give more perspective. Relief designs can be brought out to advantage, and in very many instances this factor surely should receive due consideration. I believe that Dr. Ives, when considering the distribution of il-

lumination in nature, brought our this point last year when he called to our attention how it was that towards evening the landscape presents a much more pleasant appearance, with the long and distinct though not sharp shadows.

Therefore I feel justified in considering that the true criterion applied to the direct component of semi-indirect units would be to keep the intrinsic brilliancy of the unit low enough to avoid any possible eye-strain. There will still be plenty of range for transmission. between a value for safe brilliancy, and that value which according to this paper has been found allowable (10 or 12 per cent.); and such value of the transmission component (depending upon the size of the unit) that is just safely below the limits of harmful brilliancy will be the value giving the most agreeable shadow effects and the highest efficiency.

I wish to go on record in stating my appreciation of this as being a valuable paper, pointing out, however, that the ideas contained in it must be applied with careful discretion to certain particular types of units and installations, and that the data cannot be taken as the conclusive final word on the subject leading to the design of correct semi-indirect units.

Mr. Claude W. Jordan: I have a few remarks to make regarding the apparatus used for determining the reflection coefficients of wall paints.

The use of this apparatus might involve some error, in that the parabolic reflector around the incident light source would receive the diffused reflection from the surface under examination and thus the true incident lumens on that surface would be greater than actually measured in calibrating. This fact might account for the distortion of the zero degree incident angle curve at the zero degree on the polar curve.

As to the mention made that all painted ceilings ordinarily met with being perfect diffusers, this seems rather a broad and misleading statement. It is only true in the case of paints whose pigment particles are not covered with oxidized refracting oil or any other refracting transparent medium. The use of even small amounts of linseed oil or varnish in a paint tends to impart a surface which gives specular reflection.

As to the term "specular reflection" there seems to be some

little confusion as to the physics of such reflection. On the tenth page the statement is made that highly diffused illumination tends to eliminate specular reflection. Leaving aside the regular reflection from metal surfaces, specular reflection in the sense in which it is applied in this paper, is absolutely definable and measurable.

When light rays pass from a medium of less to one of greater optical density there is always a refracted and a reflected ray. The amounts of light reflected and refracted depend upon the incident angle of the light, the refractive index of the medium of greater optical density in terms of the surrounding medium and also upon the degree of polarization of the light.

In saying that in indirect systems specular reflection does not occur, we do not convey the true facts. Specular reflection still occurs, following the laws of such reflection, but the fact that is in vogue is that the image of the light source is not apparent to the observer as the incident light is diffused. The discomfort experienced when such reflection occurs from a surface is not due to the fact that the light is specularly reflected, but is due to the great difference in intensity between the image of the light source which is formed and the diffused reflected light from the objects surrounding.

The true impression would be conveyed if, instead of saying specular reflection does not occur, it were said that the glare from specular reflection is no longer noticeable.

Mr. F. A. Vaughn: Recognizing all the limitations and inaccuracies which may accompany researches of the kind reported in this paper, the desirability of continuing this kind of work should not be overlooked. Results of investigations of this character, when intelligently interpreted by the practising illuminating engineer, are of greatest assistance and very timely. Results of this character, although as pointed out by some of the discussion they may be more or less incomplete, are in their present form and at this time when they are most desired possibly more valuable than the more complete and scientific researches on the same subjects which may have to be delayed beyond the proper psychological moment, in order to make them sufficiently accurate. The results, of course, of such investigations must be intelligently interpreted and utilized, if their full value is to

be realized, but this applies to all papers and discussion—those of the most practical form, as well as the most scientific.

Up to the present time, while recognizing the desirable characteristics and semi-indirect illumination, I have been loath to install much of this type of illumination, because of the absence of just such investigations as are here reported, feeling that, in order to use the semi-indirect system artistically and scientifically, it is necessary to have a knowledge of the adjustability of the percentages of the direct and the indirect components when applying this system to the various conditions surrounding the installation. It is believed that when these factors are thoroughly investigated, it will be possible, with the semi-indirect system, to adjust these components relative to one another in a manner to fit each character of installation, whether greatest eye efficiency, or greatest artistic qualifications, is desired.

There is also almost a complete lack of equipment, involving these adjustable features, for the use of the practising illuminating engineer, so that each type of unit must practically be designed and made up through the illuminating engineer's office.

Regarding Mr. Marks' discussion on the illumination of drafting rooms by indirect illumination, I wish to take exception to the impression which Mr. Marks' discussion would give that it is impossible to work "longer than ten minutes" under the indirect system. I have installed lighting systems in several drafting rooms, utilizing progressively more and more indirect illumination and with increasing intensities, with the idea of investigating the desirability of the indirect system for drafting rooms. These installations are all operating at the present time, and some of them have been for a year or two—all of them at least some weeks.

One installation has recently been installed which has a maximum of intensity and a maximum of diffusion, secured by placing several 45 units of 250 watts capacity, illuminating a floor space of approximately 4,200 square feet. There is practically absolute absence of all shadows, high intensity of an average of, practically, 10 foot-candles, and it has been, up to date, impossible to extract any criticism from the many men utilizing this installation, regarding the high intensity, presence of glare, or

absence of shadows. This installation is somewhat experimental and is adjustable, so that these subjects can be investigated in a practical manner.

It might be suggested that the difficulty Mr. Marks experienced with drafting rooms illuminated in this manner is due very largely to the use of the glossy side of the tracing cloth. It is appreciated that practise in this regard varies widely amongst different concerns, and it possibly is within the precinct of the illuminating engineer to make suggestions regarding this point. In the installation referred to above, the rough side of the tracing cloth is utilized, and the tint and character of the detailed paper has been suggested to the chief draftsman by the engineer.

Mr. T. W. Rolph (In reply): First, on the question of light and dark walls: The statement that dark walls are preferable was not one of the premises and does not affect the conclusions drawn. Under the consideration of the minor disadvantages of a high indirect component, the statement is made that the walls should be dark if the highest visual efficiency is to be obtained with this class of lighting, inasmuch as a high indirect component throws too much light on the walls. As far as the conclusions drawn in this paper are concerned, the statement might better have been "If dark walls are conducive to the highest visual efficiency, especial consideration should be given to them in indirect lighting, since more light is thrown on the walls than with direct lighting." The question of too much light on the walls is not of great importance in weighing the relative merits of direct and indirect lighting and is of still less, if any, importance in determining the engineering requirements of the best indirect and semi-indirect units.

Commenting on the observations on diffusion with varying percentages of direct and indirect components, Mr. Marks brought up five possible changes in conditions, which might affect the results. A large part of the discussion of the paper turns on the effect of these possible changes in conditions. I will therefore take them up in detail.

(a) *Light instead of Dark-colored Walls.*—The observations were made with varying percentages of direct and indirect components. When the illumination was totally direct, the

color of the walls had no effect whatever. This totally direct lighting was quite different from that obtained from what we ordinarily term direct lighting systems, as in the latter a considerable percentage of the illumination is received indirectly. Were the indirect component introduced in the observations the effect of lighter walls would have been to increase the efficiency with which the illumination was obtained and to increase the diffusion of the illumination due to the indirect component. Neither of these would affect the results obtained. Efficiency was of no consideration and was not measured during these observations since they were made only to determine the effects of varying proportions of direct and indirect components of the illumination. An increase in the diffusion of the indirect component would not affect the observations since this component was already so diffused as to give no shadow effect and no noticeable specular reflection in the position in which the observations were made. As far as any effect of wall color on visual efficiency is concerned, it should be noted that walls were not in the field of vision when the observer was looking at the desk and actually making the observations. In view of all these considerations, it does not seem possible that the color of the walls could have any appreciable effect on the results of these observations.

Conditions (b), (c) and (d) which Mr. Marks mentioned were change in the height of the light-unit, change in the visible area of the direct unit and change in the specific brightness of the direct unit. These three are more or less inter-dependent. If the specific brightness remains constant, increasing the height is the same as decreasing the size and vice versa, with respect to both sharpness of shadows and degree of specular reflection. If the candle-power remains constant, increasing the size is the same as decreasing the specific brightness. As the specific brightness decreases or the area increases the degree of objectionable specular reflection from working surfaces decreases. If this were carried to an extreme, as Mr. Marks suggested, we might have one or more direct lighting units, with an area as great as the area of the illuminated portion of the ceiling in indirect lighting, and a specific brightness as low as that obtained in indirect

lighting. Manifestly the illumination would be as diffused as with indirect lighting. The system would possess all the engineering advantages of indirect lighting, together with the efficiency advantage of direct lighting. At the present time, the cost of installation is the greatest bar to the development of such a system of lighting. It is evident that changing these three conditions would change the points at which shadows and specular reflection from working surfaces become objectionable. What was attempted in these observations was to obtain conditions which would represent approximately the average obtained in this class of lighting when installed primarily for its engineering advantages. With the direct source 15 inches (38.1 cm.) in diameter at the height at which this was installed and with practically perfect diffusion over the surface of the unit as obtained in this case, it seems to me we have fairly average conditions. Just what variations would be obtained by changing these conditions, I cannot state, but it does not seem probable that the changes which ordinarily obtain in practise would make any great difference in the percentages of direct and indirect components at which the effects were observed.

The fifth point (e) brought up by Mr. Marks was the effect of a change in the intensity of illumination. The illumination in these observations was three foot-candles. That was taken as representing an average illumination in places where close visual work is performed. I cannot state whether the results would be changed by changing that illumination, but it hardly seems probable that a change to 2 or 4 or 6 foot-candles would change the percentages of direct and indirect components which gave the effects observed.

It has been suggested that it would have been more accurate to measure the illumination on the ceiling to determine the flux in each zone, in the tests in the efficiency of various zones. This is true, but I believe no appreciable error was introduced by the method used. As stated in the paper, in a consideration of possible sources of error, tests which have been made on a reflector giving a somewhat similar distribution of light show little variation in candle-power at different distances from the photometer-head. I submit curves obtained from an intensive prismatic

reflector tested at distances of 4 to 30 feet (1.219 m. to 9.144 m.) from the photometer-head (fig. A).

Mr. Hibben suggested the use of a higher component of direct light for the purpose of obtaining better perspective. In offices you do not require perspective very much, but there are certain cases where you do need it badly and he mentioned one of the most important—engraving. In the lighting of a room to be

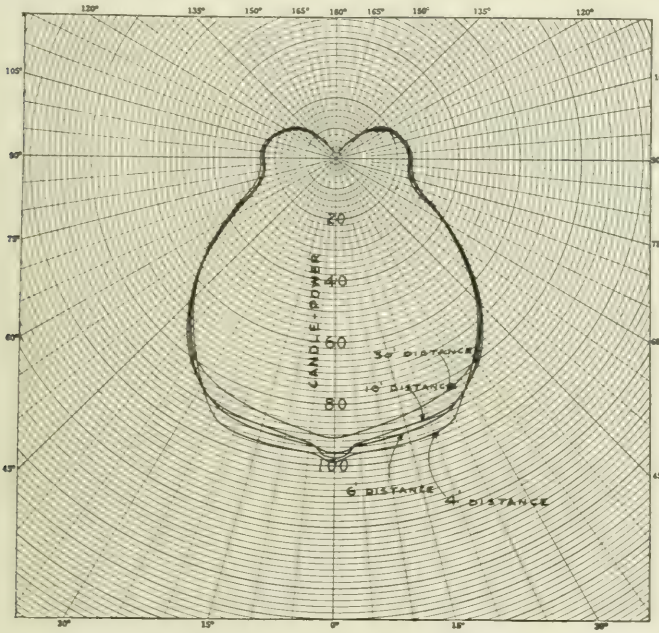


Fig. A.—Distribution from a prismatic intensive reflector with a 60-watt bowl-frosted tungsten lamp, tested at different distances from the photomer-head.

used for such a purpose, I would, by all means, recommend direct lighting. It has been found by experience to be the best, as you need sharply defined shadows in that case. It should be noted also that perspective is not entirely destroyed even by totally indirect lighting. That point has been brought out a number of times before the Society. Shadows of considerable depth are usually present in totally indirect lighting, but they lack the sharp edges which shadows due to the direct component of the light have.

Mr. Hibben also brought up the question of artistic considerations. This paper is not intended to cover and does not apply to conditions where artistic considerations are of importance. It is an engineering paper purely and the results should be applied principally to places where the diffusion obtained with this system of lighting is of the greatest moment—primarily such rooms as offices, reading-rooms, etc. In cases where artistic considerations are prominent it might be desirable to have a higher percentage of transmitted light, provided you do not wish to obtain the engineering advantages of the indirect component.

Mr. Jordan suggested that with the apparatus for testing diffusion and coefficient of reflection illustrated in fig. 4, there might be an error due to light reflected from the disk striking the reflector and being reflected back to the disk. The diameter of the reflector is 11.5 inches (0.284 m.) and its distance from the disk is 3.86 feet or 46.3 inches (1.177 m.). It subtends a solid angle of 0.025 steradians. As the disk reflects light through a solid angle of 2π steradians it will be seen that the reflector subtends less than ½ of 1 per cent. of the solid angle through which the disk spreads its light. Furthermore very little of the light which the disk reflects to the reflector would be reflected back in the direction of the disk. It will be apparent therefore that this possible source of error is negligible.

Mr. Jordan also brings up the point that where oil paints are used on ceilings, the diffusion is not as shown in figs. 5 and 6. That is true, but as stated in the paper, rooms in which indirect or semi-indirect lighting is likely to be used for its engineering advantages, only in rare cases have ceilings finished with oil paint or any material giving a glossy surface.

Mr. Jordan made a very good distinction between specular reflection and glare due to specular reflection. Specular reflection from working surfaces is present in as great degree with indirect lighting as with direct lighting, but the reflected light is not directed in objectionable directions. In the paper, where the term "specular reflection from working surfaces" is used, the specular reflection due to direct light is meant, and I think the context will convey the proper impression, although it could have been stated more exactly.

I may have overlooked some of the points brought up in the discussion but many of them are covered in the paper and could not be brought out in abstracting it. The conclusion which has been questioned the most seriously is that the direct component of the illumination should not be greater than approximately 15 per cent. of the total illumination. The suggestion was repeated from a previous paper that the ratio of equal parts direct and indirect components of the illumination is desirable. An increase in the direct component from 15 per cent. to 25 or 30 per cent. means very little increase in efficiency, as the greater transmission downward does not make up for the accompanying greater transmission near the horizontal where the light is used less efficiently than in any other direction. If the direct component of the illumination is increased to 50 per cent. there will probably be an appreciable increase in efficiency. I take it, that some such system was used in the tests Mr. Spaulding referred to. He did not mention the character of the opal glass used. However, with a 50 per cent. direct component, it is doubtful whether the system ought to be called semi-indirect lighting or an inefficient form of direct lighting. Opal balls, for example, as ordinarily installed give a direct component of less than 50 per cent. With bare lamps in a room having light ceiling and medium walls, illumination tests show a direct component of only approximately 40 per cent. We do not ordinarily realize how large the indirect component is, with what we usually term direct lighting. For rooms in which semi-indirect lighting is of value for its engineering advantages, the only evidence we have in favor of a direct component of 30 to 50 per cent. is that such installations have been made and look all right and give satisfaction. The same thing can be said of direct lighting systems. They have been installed in offices, reading-rooms, etc., and have given perfect satisfaction. We are now considering, however, a system which promises much better illumination, for the purpose, than direct lighting gives. Accompanying this improvement in illumination is a great increase in operating cost. Now, the argument in favor of a direct component of not over approximately 15 per cent. is based primarily on the statement that, to justify this great increase in operating cost, the illumination advantages of the system should be obtained as fully

as possible. To show that 15 per cent. direct component is approximately the high limit at which those advantages are obtained as fully as possible, four classes of evidence are introduced. First a line of reasoning based on the entire elimination of objectionable specular reflection from the direct component; second, a line of reasoning based on the reduction of the intrinsic brilliancy of the unit to a desirable point; third, a series of observations on specular reflection from various percentages of direct component under approximately average conditions; and fourth, a series of observations on shadows obtained with varying percentages of direct component under average conditions. These four classes of evidence all point to approximately the same high limit of direct component. While the evidence may not be conclusive in favor of a direct component of not over approximately 15 per cent., it seems to me to far outweigh any other evidence so far brought forward.

As brought out in the discussion and also in the paper, the prototype curve cannot be taken as the exact curve which must be obtained. The effect of variations from the curve is pretty well covered on the next to the last page of the paper. As a matter of fact, the curve could not be obtained exactly; it can only be approximated. It is given here merely to show what the evidence so far brought out, indicates as the most desirable curve to work to in the design of indirect and semi-indirect light-units.

THE LIGHTING OF THE BUFFALO GENERAL ELECTRIC COMPANY'S BUILDING.*

BY W. D'A. RYAN.

The following brief description will answer as a guide to the members of the Illuminating Engineering Society when visiting the Buffalo General Electric Company's new office building.

The building which was designed by Esenwine & Johnson, local architects, consists of a main structure of four stories, surmounted by an octagonal tower of fourteen stories rising to a total height of approximately 300 feet. The entire building is glazed white terra cotta and is of the most modern fire-proof construction. The basement, first and mezzanine floors will be occupied by the Buffalo General Electric Company, and the remaining space will be sub-let for general offices.

The lighting specifications were drawn by the illuminating engineering department of the General Electric Company, Schenectady, N. Y. This is one of the first important buildings in which the illuminating engineer was made responsible, not only for the design and location of the lighting units, but also passed upon other features having an important bearing upon the general lighting effect, such as interior finish and decorations, window shades, etc.

From the beginning it was understood that the lighting of both interior and exterior should be distinctive and fully representative of the latest development in the art, marking if possible an era in high-class office building lighting.

Owing to the monumental character of the building and the general construction outlining with small units was out of the question. It was, therefore, decided to use white light furnished by the 6.6 ampere series ornamental luminous arc lamps spaced around the building at the curb line, along the top of the main structure and on the cappings at the tower steps on the 14th, 15th and 16th floors. A five-light 30-foot standard of these luminous lamps was also placed in the center of the aisle of

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

safety as illustrated. The effect at night is that of a white building, relieved by the warm yellow light of the tungsten lamps streaming through the windows, rising to a colonade illuminated by concealed blue purple light in simulation of

Fig. 1.—Night view of the Buffalo General Electric Company Building.

shadow effect, contrasted with the white light thrown on the outer surface of the columns by the luminous arc lamps; the whole, surmounted by revolving searchlight beams 300 feet above the street. The latter effect is produced by three 30 inch (0.76

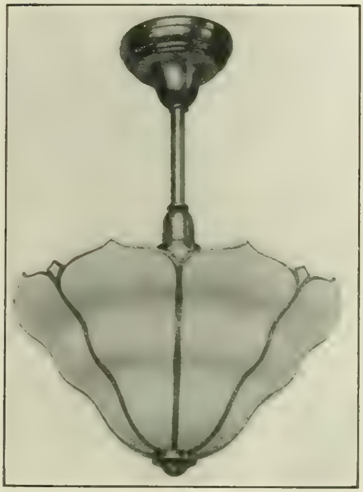
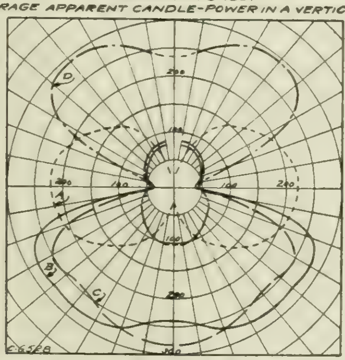


Fig. 2.—Semi-indirect lighting fixture No. 1409½.

	A	B	C	D
FIXTURE	NONE	DIRECT	DIRECT	SEMI-INDIRECT
LAMP	CLEAR	CLEAR	B F	CLEAR
VOLTS	110	110	110	110
AMPERES	2.27	2.27	2.27	2.27
WATTS	250	250	250	250
MEAN UPPER HEMISPHERICAL C P	170	57.4	62.4	184
WATTS PER MEAN UPPER HEMISPHERICAL C P	1.47	4.36	4.00	1.36
MEAN UPPER HEMISPHERICAL C P PER WATT	0.68	0.23	0.25	0.74
MEAN LOWER HEMISPHERICAL C P	173	227	197	69.8
WATTS PER MEAN LOWER HEMISPHERICAL C P	1.44	1.10	1.27	3.58
MEAN LOWER HEMISPHERICAL C P PER WATT	0.69	0.91	0.79	0.28
MEAN SPHERICAL C P.	172	142	130	127
WATTS PER MEAN SPHERICAL C P	1.45	1.76	1.93	1.97
MEAN SPHERICAL C.P. PER WATT	0.68	0.57	0.52	0.51

PHOTOMETRIC TEST
AVERAGE APPARENT CANDLE-POWER IN A VERTICAL PLANE



READINGS TAKEN AT 10 FT RADIUS
CLEAR LAMP OPERATED AT 221 HORIZONTAL C.P
WATTS PER HORIZONTAL C.P 1.13
BOWL FROSTED LAMP OPERATED AT 208 HORIZONTAL C P
WATTS PER HORIZONTAL C.P. 1.20
LEADED "SPECTROWHITE" GLASS SHADE 17" DIA. X 8½" DEEP
AMBOY NO. 3370.

Fig. 3.—Photometric distribution curve from semi-indirect lighting fixture No. 1409½ shown in fig. 2.

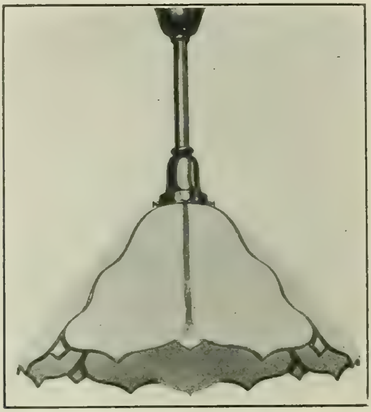
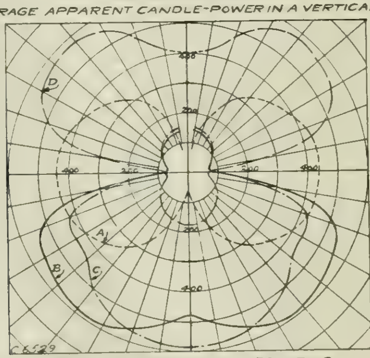


Fig. 4.—Direct lighting fixture No. 1409.

	A	B	C	D
FIXTURE	NONE	DIRECT	DIRECT	SEMI-INDIRECT
LAMP	CLEAR	CLEAR	B.F	CLEAR
VOLTS	110	110	110	110
AMPERES	4.54	4.54	4.54	4.54
WATTS	500	500	500	500
MEAN UPPER HEMISPHERICAL C.P	364	100	106	450
WATTS PER MEAN UPPER HEMISPHERICAL C.P	1.38	5.00	4.71	1.11
MEAN UPPER HEMISPHERICAL C.P. PER WATT	0.73	0.20	0.21	0.90
MEAN LOWER HEMISPHERICAL C.P	364	472	405	110
WATTS PER MEAN LOWER HEMISPHERICAL C.P	1.37	1.06	1.24	4.54
MEAN LOWER HEMISPHERICAL C.P PER WATT	0.73	0.95	0.81	0.22
MEAN SPHERICAL C.P	364	286	256	280
WATTS PER MEAN SPHERICAL C.P	1.38	1.75	1.96	1.79
MEAN SPHERICAL C.P PER WATT	0.73	0.57	0.51	0.56

PHOTOMETRIC TEST

AVERAGE APPARENT CANDLE-POWER IN A VERTICAL PLANE



READINGS TAKEN AT 14 FT RADIUS

CLEAR LAMP OPERATED AT 442 HORIZONTAL C.P

WATTS PER HORIZONTAL C.P 1.13

BOWL FROSTED LAMP OPERATED AT 389 HORIZONTAL C.P.

WATTS PER HORIZONTAL C.P 1.28

LEADED "SPECTROWHITE" GLASS SHADE 20" DIA. X 8½" DEEP

AMBOY NO. 2860

Fig. 5.—Photometric distribution curve from direct lighting fixture No. 1409 shown in fig. 4.

m.) projectors mounted on a revolving platform in the dome; the projectors are also provided with motors, so that they revolve on their own centers through color evolutions produced by screens mounted on projectors.

The general interior illumination is semi-indirect, the fixtures being especially designed for this building. The watts per square foot for the entire building average 1.4. The total area including all space is 76,800 square feet and the connected load 108

Fig. 6.—Contract department.

kilowatts. The foot-candles are not less than 4 or over 6, except in a few special cases, as in the draughting-room where it is slightly higher. The main units in the offices throughout are of the convertible type, making it possible for the respective tenants to have either direct or semi-indirect lighting, as the desire.

The units on the 13th, 14th and 15th floors are of special design and are made to throw a strong light through the heavily latticed windows and at the same time light the room with semi-indirect illumination.

Tests have not been completed but sufficient data have been compiled to give a fair approximation of the general efficiency of the system.

Fig. 7.—The rotunda.

Plans of the floors of the building showing the locations and sizes of the light units together with diagrams showing the watts per square foot for the various floors and rooms are given on the following pages.

TABLE OF ILLUMINATION TEST RESULTS.

Lighting unit	Total watts	Floor area sq. ft.	Watts per sq. ft.	Avg. foot-candles	Lumens per watt	Ratio Min./avg.	Max./avg.	Min./max
Semi-indirect unit with 250 watt clear tungsten lamp......	1,000	465	2.15	8.12	3.78	0.86	1.17	0.74
Semi-indirect unit with 150 watt clear tungsten lamp..	600	465	1.29	4.31	3.34	0.81	1.11	0.73
Semi-indirect unit with 250 watt clear tungsten lamp..	500	360	1.39	4.67	3.36	0.66	1.55	0.42
Semi-indirect unit with 150 watt clear tungsten lamp..	1,200	780	1.54	5.20	3.38	0.67	1.21	0.55
Semi-indirect unit with 150 watt clear tungsten lamp..	600	360	1.66	5.02	3.02	0.90	1.11	0.80

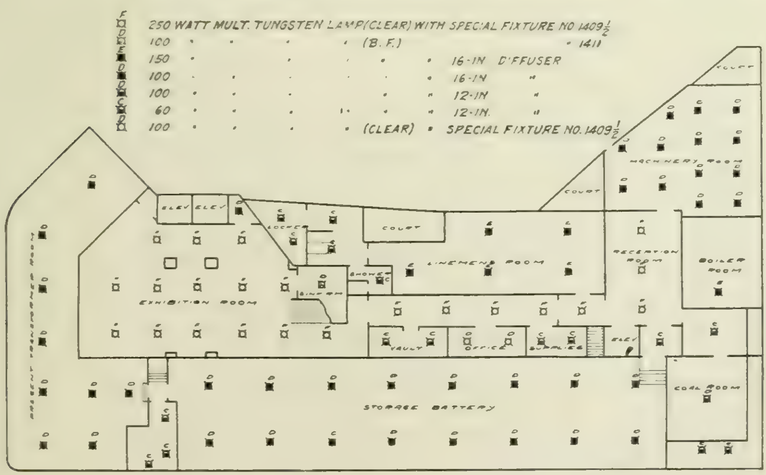


Fig. 8.—Plan of the basement.

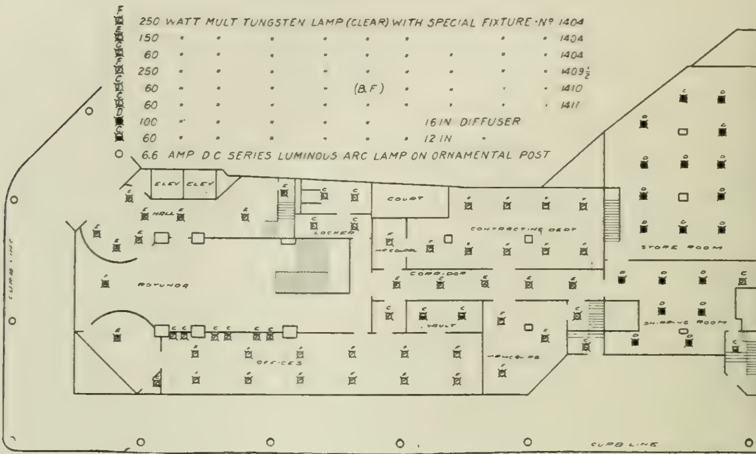


Fig. 9.—Plan of first floor.

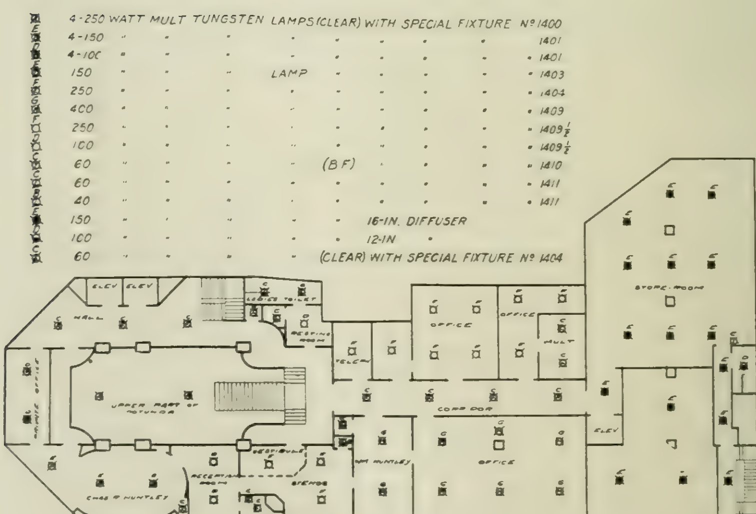


Fig. 10.—Plan of mezzanine floor.

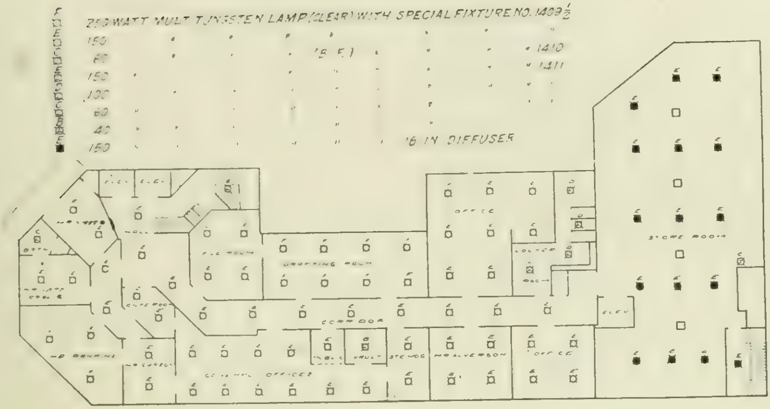


Fig. 11.—Plan of second floor.

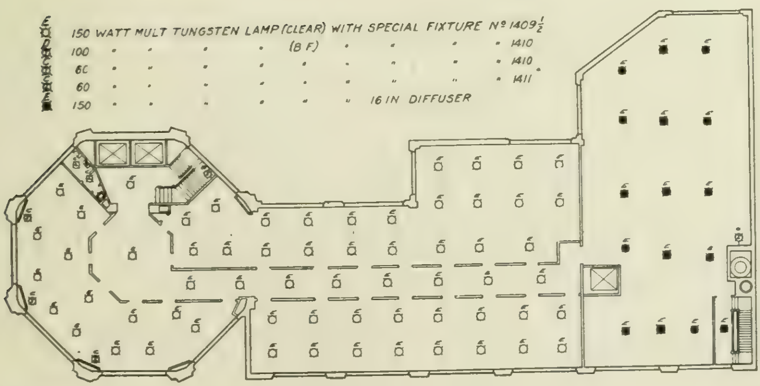


Fig. 12.—Plan of third floor.

F 250 WATT MULT. TUNGSTEN LAMP (CLEAR) WITH SPECIAL FIXTURE Nº 1409
E 150 " " " " " " " " " 1409½
C 60 " " " " (B F) " " " " 1410
C 60 " " " " " " " " " 1411

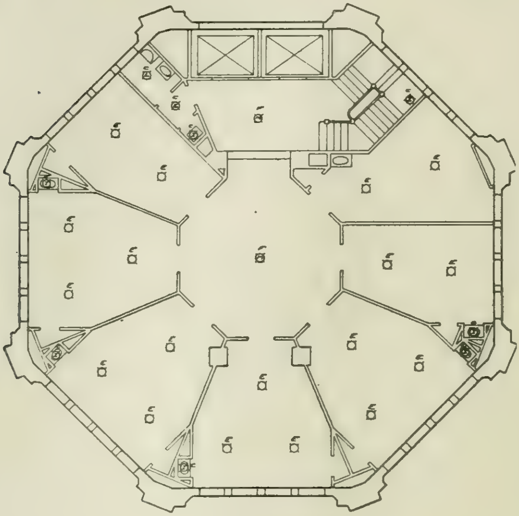


Fig. 13.—Plan of fourth floor.

F 250 WATT MULT. TUNGSTEN LAMP (CLEAR) WITH SPECIAL FIXTURE NO. 1409½
C 60 " " " (B.F.) " " " 1410
C 60 " " " " " " " " 1411
E 150 " " " " (CLEAR) " " " " 1409½

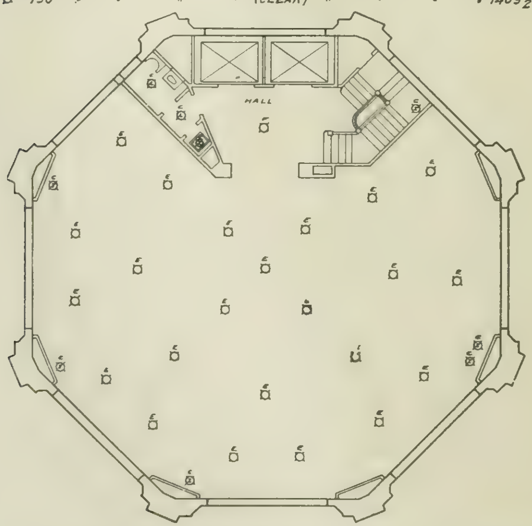


Fig. 14.—Typical plan of the fifth, sixth, ninth, tenth and eleveuth floors.

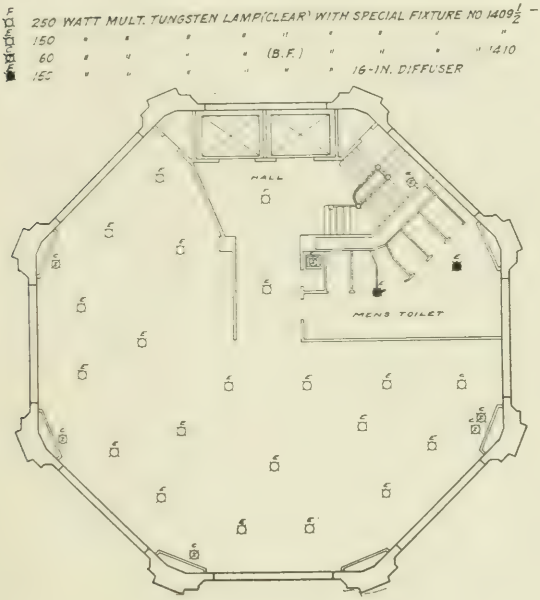


Fig. 15.—Plan of seventh floor.

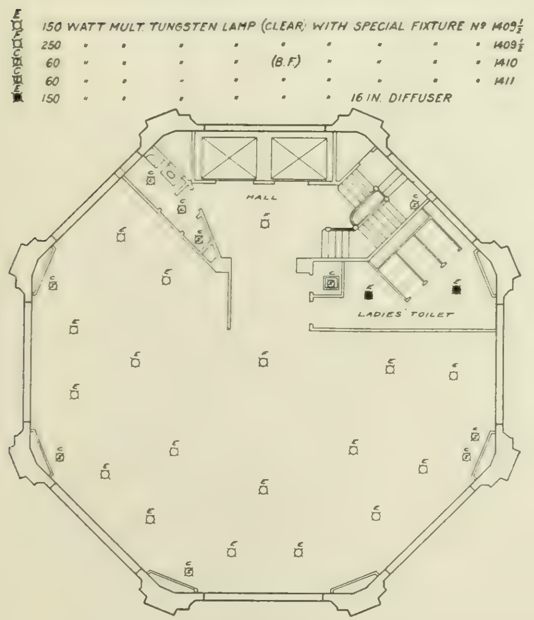


Fig. 16.—Plan of the eighth floor.

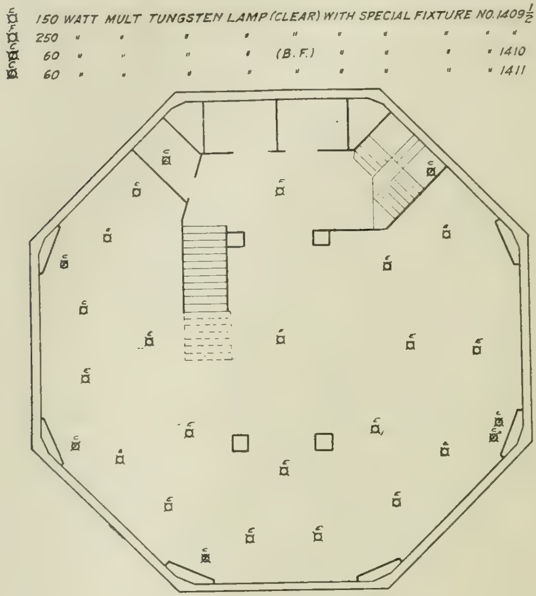


Fig. 17.—Plan of the twelfth floor.

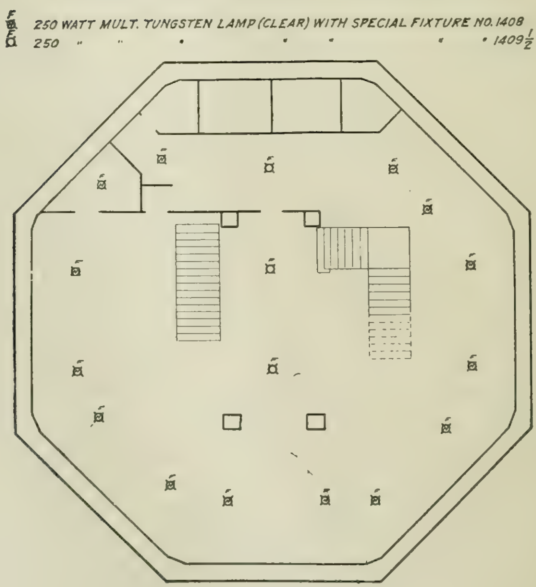


Fig. 18.—Plan of the thirteenth floor.

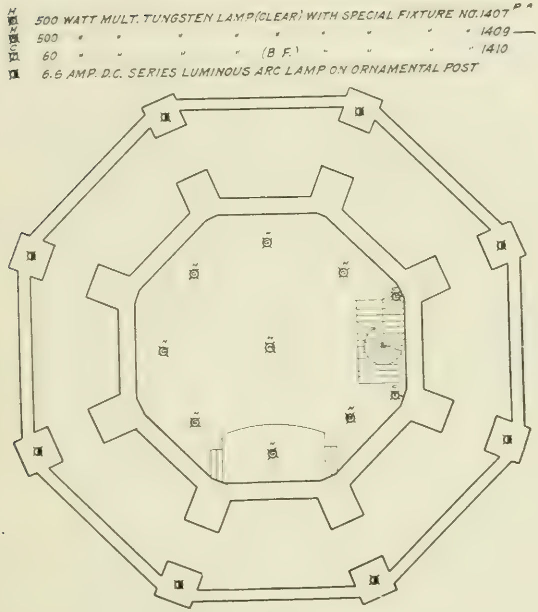


Fig. 19.—Plan of the fourteenth floor.

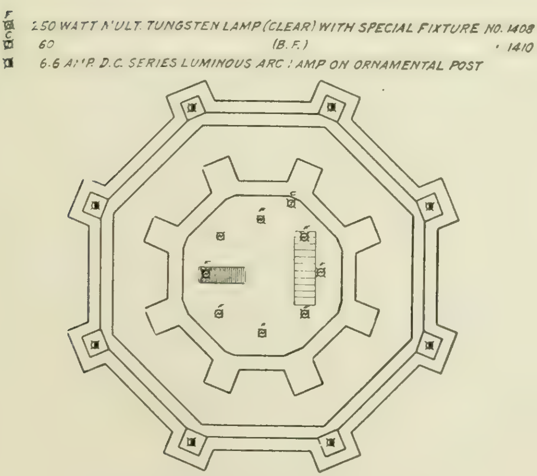


Fig. 20.—Plan of the fifteenth floor.

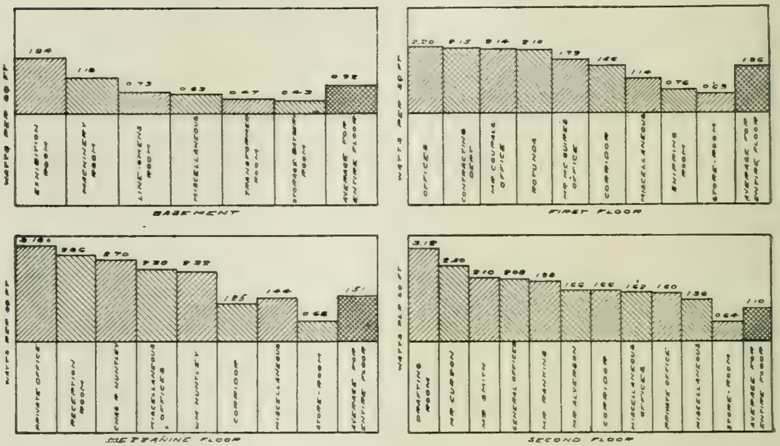


Fig. 21.—Energy diagram of the general lighting on basement, first, mezzanine and second floor.

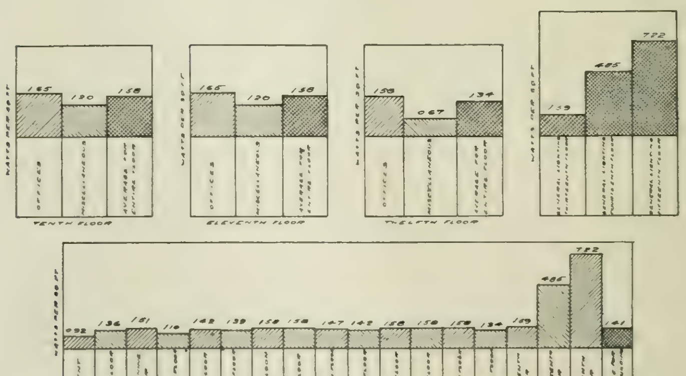


Fig. 22.—Energy diagram of the general lighting on tenth, eleventh and twelfth floors. Watts per square foot (lower half of diagram) for all floors.

Fig. 23.—Special fixture No. 1400.

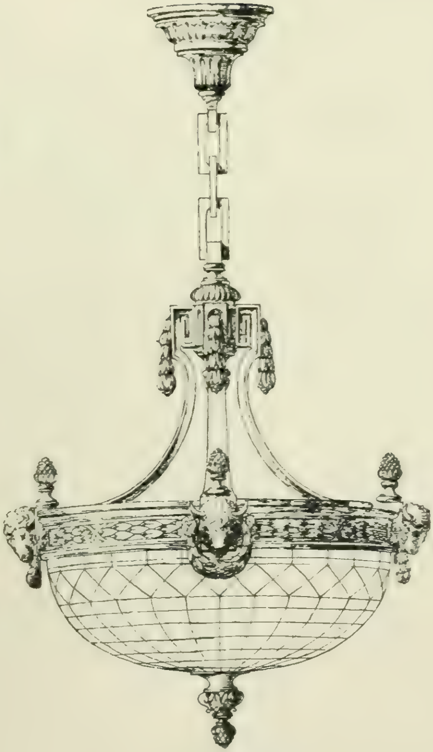


Fig. 24.—Special fixture No. 1401.

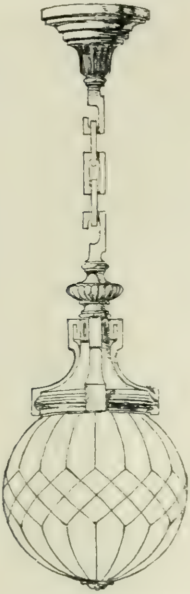


Fig. 25.—Special fixture No. 1403.

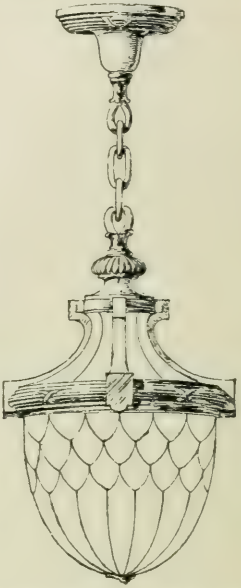


Fig. 26.—Special fixture No. 1404.

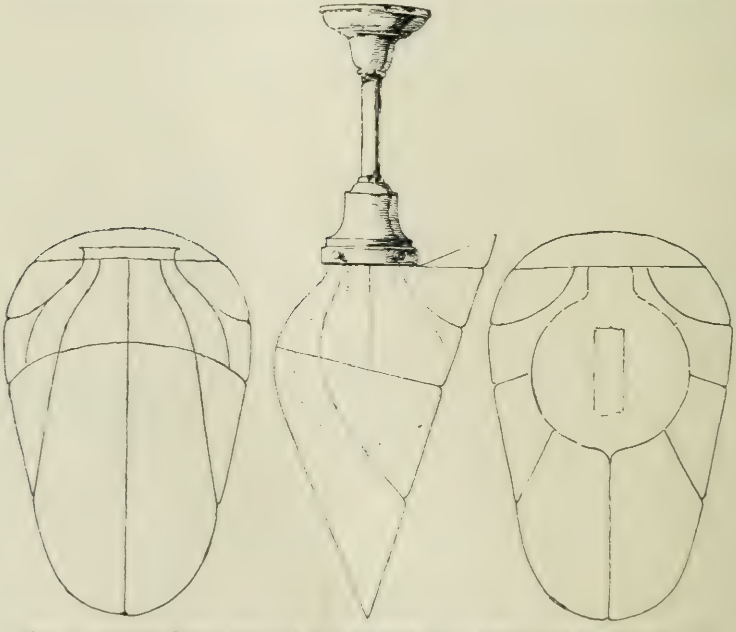


Fig. 27.—Special fixture No. 1407 with 500-watt lamp; fixture 1408 same as No. 1407, but equipped with a 250-watt lamp.

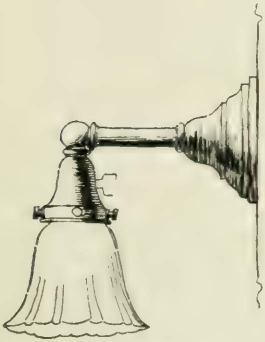


Fig. 28.—Fixture No. 1410.

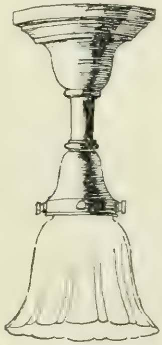


Fig. 29.—Fixture No. 1411.

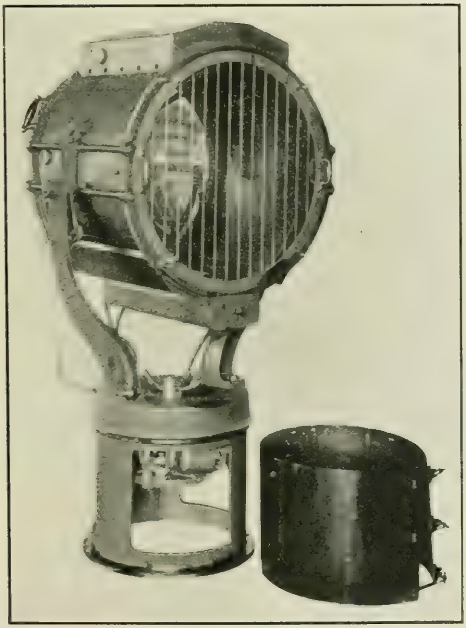


Fig. 30.—30-inch special projector lamp used in tower.

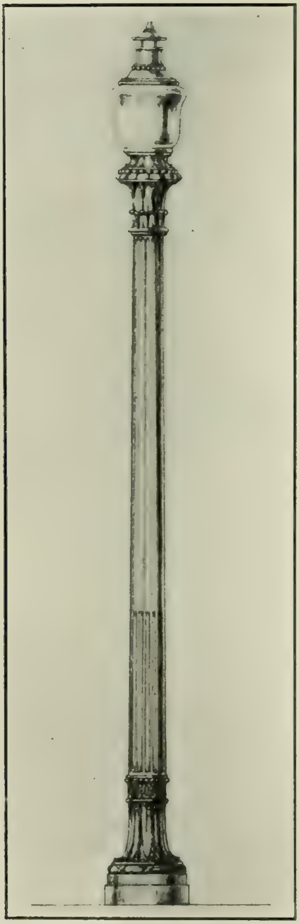


Fig. 31.—Ornamental post with an ornamental luminous arc lamp.

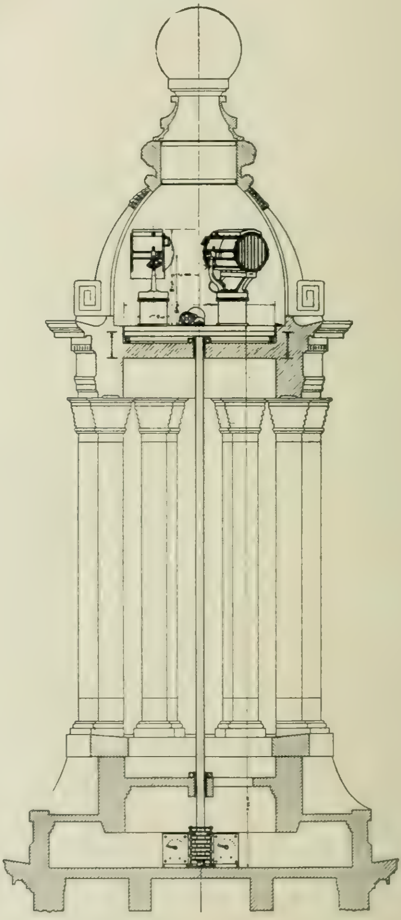


Fig. 32.—Cross section of the tower of the building.

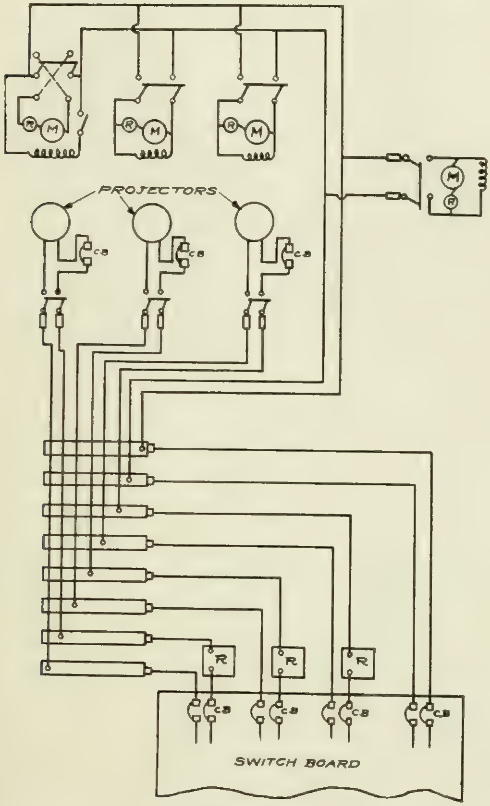


Fig. 33.—Diagram of the electrical connections for the tower lighting.

DISCUSSION.

Mr. G. H. Stickney: I have talked with some of those who have worked under the lighting in some of the offices of this building and they have spoken very highly of it. The fixtures certainly make a nice appearance in the day time; I have not seen them at night.

This installation is the result of co-operation between the illuminating engineer and the artistic designer and has some notably unique features which are sure to excite considerable interest.

I have not had an opportunity of analyzing the figures carefully, but I note that the efficiency, as expressed in lumens per watt, is remarkably high for semi-indirect lighting.

THE DIFFUSE REFLECTION AND TRANSMISSION OF LIGHT.*

BY P. G. NUTTING.

INTRODUCTION.

The distribution of light is profoundly affected by diffusely reflecting or transmitting screens. The best distribution of illumination requires the use of three different types of diffusing screens and illuminating engineers demand of each the highest attainable efficiency. The three types of diffusion required are:

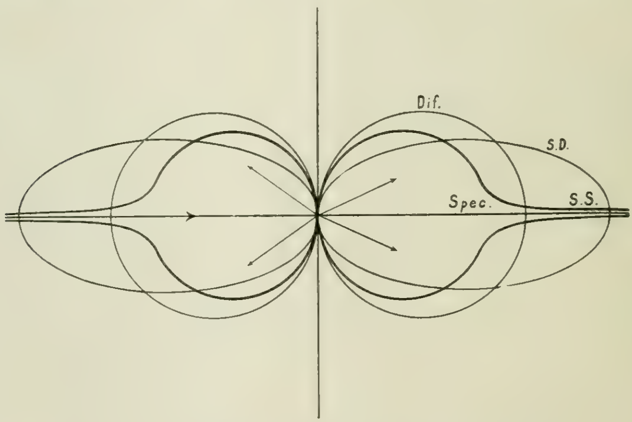


Fig. 1.—Varieties of diffuse reflection and transmission.

1. Transmission with maximum diffusion and minimum absorption of light. Such screens (lamps, bulbs and globes) are required to reduce the intrinsic brilliancy of sources with minimum loss of light.

2. Diffuse reflection with both reflecting power and diffusion a maximum. Such properties in wall coverings not only save light but give a more uniform illumination with fewer fixtures.

3. Diffuse reflection with high reflecting power but with the reflected light massed within a given angle. Reflection of this type (aluminum paint) gives light economy in indirect illumination and projection screens.

In a laboratory survey of these problems we find examples of

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

practically all varieties of diffuse reflection and transmission (Fig. 1).

There are the purely specular, the semi-specular, the selectively diffuse and the perfectly diffuse or Lambert Law distributions of both reflected and transmitted light. Practically any amount of absorption may occur with any type of diffusion. Each case of diffusion may be traced to particular kinds of reflection, refraction and diffraction within or near the surfaces of bodies.

THE PHYSICS OF DIFFUSION.

The various substances causing the different types of scattering met with in the laboratory owe their properties to peculiarities in structure. Before proceeding to the mathematical theory of the subject, a few concrete cases of each type will be reviewed and interpreted.

1. *Specular Reflection and Transmission.*—Imbedded opaque particles of molecular dimensions cannot cause diffusion of light. Such particles may profoundly affect the absorption of the light waves but cannot alter their direction except indirectly through refraction. Scattering begins as the particles approach in dimensions the length of a light wave. This limit, say one-fifth of a wave length or $100\mu\mu$ is just below the working range of the ordinary microscope, though with the ultra-microscope (an ordinary microscope with purely oblique illumination) diffraction disks may be obtained from particles fifty times smaller or $2\mu\mu$ in diameter. Molecular dimensions are of the order of $0.1\mu\mu$, $^1/_{20}$ of the lower limit of the ultra-microscope and $^1/_{1000}$ of the lower limit of particles causing diffusion.

Gold ruby glass and various classes of colloidal suspensions of metals are familiar examples of substances that contain particles visible with the ultra-microscope and yet not sensibly diffusing in mass. It is an interesting experiment on the transition from a specular to a diffuse reflection to mix dilute solutions of ordinary hyposulphite and sulphuric acid. The precipitated sulphur forms in larger and larger aggregates, giving the suspending liquid all degrees of turbidity.

2. *Semi-specular Reflection and Transmission.*—Examples of mixed specular and diffuse reflection are seen in glass surfaces lightly dusted with powder or very lightly frosted by etching,

sand blasting or grinding. The distribution of the diffusely reflected portion of the light follows Lamberts Law rather closely while the specularly reflected portion follows the laws of specular reflection. An extreme case of this type is a perfectly diffusing surface which has been flowed over with a reflecting transparent varnish or a white opaque sediment over which water is standing. This gives a combination of nearly pure specular and pure diffuse reflection.

Slight diffusion by transmission is familiar in slightly turbid media particularly in the atmosphere when free from fog or clouds. Diercks[1] has recently published data on the falling

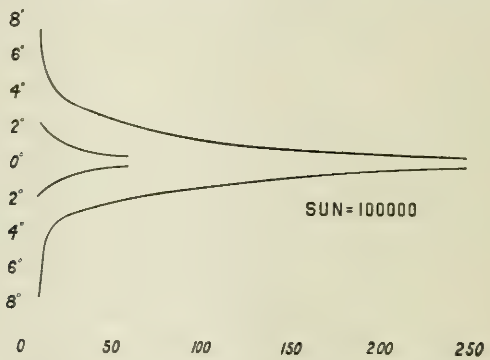


Fig. 2.—Decrease in sky brightness from the sun's limb outward.

off in the brightness of the sky from the sun's limb outward. (Fig. 2.)

This shows the characteristic diffusion due to diffraction near the direct path of the rays falling rapidly, at about 5 deg. from the sun, to a nearly uniform distribution of light corresponding roughly to Lambert's law.

A frosted sheet of glass may of course be prepared to give nearly all proportions of directly and diffusely transmitted light.

3. *Perfectly Diffuse Reflection and Transmission.*—Surfaces which reflect or emit in close accordance with Lambert's Law are not uncommon. The essential condition is that the orientation of the individual reflecting or emitting particles comprising the surface be indifferent, as many facing each direction as face any other; such surfaces are not difficult to prepare.

[1] *Physik. Zeit.*, vol. 13, p. 502-4, June 15, 1912.

The minimum absorption of a surface comprised of transparent particles such as snow, powdered boric acid and the like appears to be about 15 per cent. The corresponding figure for surfaces composed of metallic particles has not yet been determined. The metal paints exhibit far from perfectly diffuse reflection.

A close approach to perfectly diffuse transmission is rare among ordinary laboratory materials. Both surfaces are concerned in the diffusion and a trace of dirt on either surface modifies the diffusion considerably. The nearest approach to a useful perfectly diffusing transmission screen is a sheet of opal glass ground on both sides. A sheet of clear glass, frosted on both sides, gives far from perfectly diffuse transmission.

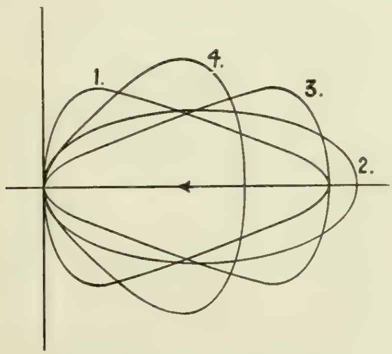


Fig. 3.—Types of selective diffusion.

4. *Selectively Diffuse Reflection and Transmission.*—These are more commonly met with than any other kind. Any departure from perfect regularity or perfect irregularity in the roughness causing scattering will throw more light in some directions than in others.

The plot of the distribution of reflected or transmitted light is more or less elliptical ranging from egg shaped point outward through the purely elliptical to the egg shaped point inward (fig. 3). The latter is of course the type most desired in illumination.

Heavily calendered paper exhibits this peculiarity quite generally as does a flat surface painted with flaky metal paint. A mat surface rolled or pressed against a plane surface or a specu-

lar surface that is slightly wavy gives maximum reflection within a given angle. The various corrugated and prismatic glasses give a wide range of distribution to the transmitted light.

With highly colored materials not only the *amount* but the *diffusion* and *polarization* of reflected light varies enormously with the wave-length. The surface appears colored because of the excess of reflecting power for certain wave-lengths. These same wave-lengths must be admitted most freely within the surface, since the reflection of the complementary wave-lengths directly for the outer surface can in general (metals excepted) be only about a tenth as great as of the waves diffusely reflected from beneath the surface. Hence light of the characteristic color of the surface is strongly reflected, highly diffused and but slightly polarized; while its complementary color is weakly and specularly reflected and at most angles highly polarized. For example a red, semi-mat wall paper shows in a spectroscope say red, orange and yellow strongly reflected, and green, blue and violet but faintly reflected. Red light reflected from such a paper will be found highly diffused and almost unpolarized, while blue light is faintly reflected from the outer surface alone and hence more or less specularly reflected and highly polarized, except when reflected at nearly perpendicular incidence.

A variation of color at or near the angle of specular reflection is the ordinary case with mat or semi-mat non-metallic surfaces. On the other hand the light reflected from semi-mat metallic surfaces, like copper and gold, analyze the same color at the angle of specular reflection as at any other angle.

Polarization must be taken account of in the testing of reflecting materials; but it is of little consequence in illuminating problems, except where light is to be twice reflected from material with a strongly selective reflecting power.

THEORY OF DIFFUSION.

It is for the theory of diffusion to determine the distribution of the reflected or transmitted light when a given pencil of light strikes a given surface. In general the microscopic details of a surface are all different and the theoretical problem of light distribution is indeterminate, but it is worth while to consider a few assumed but not impossible cases in which the surface is either

homogeneous or else perfectly heterogeneous in certain characteristics. One is most concerned with the case of homogenity of *material* combined with heterogenity of *size, form* and *orientation* and he may wish to find the reflecting-power and diffusion.

Consider first a layer of reflecting spheres, each sphere small compared with the distance of the source of illumination and the point of view. One may think of a tray covered with steel balls, the free surface of a mass of bubbles, mercury globules in balsam, or a surface frosted with condensed vapor.

Each little sphere (fig. 4) forms a tiny image of the source. The specific *brightness* of each image, by an elimentary law of geometrical optics, is that of the source, multiplied by the reflecting

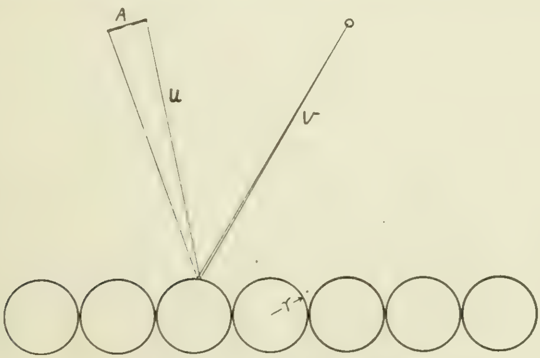


Fig. 4.—A graphic representation of diffuse reflection.

power of the surface of the sphere. The size of each image is proportional to the radius of each sphere, hence the area of each image is proportional to the square of that radius. But the whole number of spheres, if closely packed, is inversely proportional to the square of the radius of each; hence the brightness of our layer of spheres as a whole is independent of their size and proportional to the reflecting power of each at the particular angle at which reflection takes place.

In mathematical terms, assume a source of light of area A and specific brightness B at a distance u from a reflecting surface composed of reflecting spheres of radius r packed in a plane. Then the brightness B′ of the small image formed by each sphere is such that

$$B' = BR \tag{1}$$

R being the reflecting power of the surface of the sphere given in terms of angle and refractive index by the familiar Fresnel formulae.

Again, the ratio $\frac{y'}{y}$ of the linear dimensions of image and source is, assuming *r* small compared with *u*.

$$\frac{y'}{y} = \frac{r}{2u}. \tag{2}$$

The relative areas of image and source are then

$$\frac{A'}{A} = \frac{y'^2}{y^2} = \frac{r^2}{4u^2}. \tag{3}$$

But the ratio of all the areas of all the images to total area of surface is $\frac{A'}{4r^2}$, hence the mean brightness of the illuminated surface as a whole (call it B_o) is to the brightness B' of each image in the ratio

$$\frac{B_o}{B'} = \frac{A'}{4r^2} = \frac{Ar^2/4u^2}{4r^2} = \frac{1}{16}\,\frac{A}{u^2}, \tag{4}$$

making use of (3). Hence, by (1), the relative brightness of illuminated surface and source is

$$\frac{B_o}{B} = \frac{1}{16}\,\frac{A}{u^2}\,R = \frac{\omega}{16}\,R \tag{5}$$

since A/u^2 is the solid angle subtended at each sphere by the source.

Such a surface composed of small reflecting spheres would then reflect in accordance with Lambert's Law except as the reflecting power (specular) of each sphere varied with the angle of incidence; the co-efficient of diffuse reflection would be $\pi R/8$, neglecting multiple reflection from sphere to sphere.

Consider next the case of a mass of minute plane reflecting surfaces spread loosely in an approximate plane. Such conditions might be realized with say a mass of fine silver crystals, every face of which is a small plane. Suppose none of the faces are very much larger than the mean and suppose that the orientation of the faces is entirely indifferent—as many face any given direction as face any other.

The probability of any face reflecting light in a given direction is therefore proportional to the area of the source; it is the

ratio of the solid angle subtended by the source (say ω) to the whole spherical area 4π. The probability of a given crystal having a face reflecting outward is then $\omega/2\pi$.

If the mean reflecting power (mean at all angles of incidence) of the faces is R then the relative brightness of surface and source is $R\omega/2\pi$, under the assumption that the field of view is completely filled by the various reflecting faces and that all of the light reflected inward is absorbed. Under the same assumptions, the coëfficient of diffuse reflection would be ($\omega = 2\pi$) simply R, the mean reflecting power of a single face.

To take account of the mean foreshortening of the reflecting faces, one must multiply by the mean value of the cosine, 0.63; hence, simply ignoring multiple reflection, the coëfficient of diffuse reflection would be 0.63 R. Multiple reflection would raise this coëfficient by an amount not readily calculated; hence it can only be said that the actual reflecting power of the surface will be between 0.63 R and R.

If a plane surface be pressed against such a loose mass of crystals, obviously their mean orientation will no longer be neutral and the probability law will no longer apply. There will then be a more or less dominant specular reflection superposed on the lowered diffuse reflection.

The theory of reflection from surfaces composed of small *transparent particles*, such as snow and other crystals for example, may be treated in the same manner and leads to the same numerical results, except that the reflecting power R is to be interpreted in this case as the coëfficient of total reflection less the mean loss by reflection from a single face; hence R is equal to about 0.90. The highest recorded reflection coëfficients are about 86 per cent.; so that the percentage of light ultimately lost by transmission inward is very small when the particles themselves are highly transparent.

The three simple cases outlined above are all that lend themselves readily to mathematical treatment. In all three, theory indicates that reflection following Lambert's Law is to be expected. More extended theory would involve a more precise knowledge of physical properties, a treatment of multiple reflection, and the theory of probabilities in ways that are not promising of fruitful results.

DISCUSSION.

Dr. C. H. Sharp: This paper by Dr. Nutting presents a very precise and short method of arriving at coefficients of reflection. It is interesting in that it involves the practical application of the theorem that the flux density of light from an infinite plane remains constant as you go away from that plane.

Mr. M. Luckiesh: Inasmuch as Dr. Nutting does not show any diffusion curves for actual commercial glasses, the accompanying figure should be of interest. I have examined quite a number of flat samples. Those whose diffusion curves are shown in the illustration are briefly described as follows:

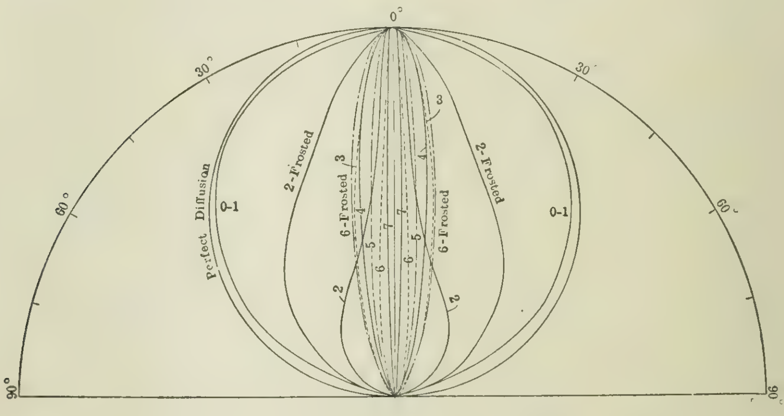


Fig. A.—Diffusion curves obtained from several commercial glasses.

0-1	Thin flashed opal.
2	Pressed Alba ¼ inch thick.
2 (frosted)	Same frosted.
3	Etched white acid.
4	Incandescent lamp frosting.
5	Rough pressed lime.
6	Lucida ⅛ inch thick.
6 (frosted)	Same frosted.
7	Pressed lime.

All samples examined which owe their diffusing property to the character of their surface alone exhibited diffusion curves like that marked S. D. in fig. 1 of Dr. Nutting's paper. The thin milk opal glass approaches perfect diffusion. The type of glass known as Alba shows a curve like S. S. Lucida glass shows this characteristic only very slightly even in thicknesses of ¼ inch.

THE PERCEPTION OF LIGHTS OF SHORT DURATION AT THEIR RANGE LIMITS.

BY A. BLONDEL AND J. REY.*

OBJECTS OF INVESTIGATION.

The laws of the perception of lights of short duration are of very great interest, not only from a theoretical and philosophical point of view, but also by reason of the important applications to which rapid signals give rise in practise. Accordingly, numerous investigators—Helmholtz, Brücke (1886), Exner (1868), Allard (1872), Kunkel (1874), Swan (1849), Charpentier (1887-1890) Broca and Sulzer (1902), Martins (1902), Mac Dougall (1904), et. al.—have devoted themselves to a study of the variation of the luminous sensation in time function. The most complete and most scientific knowledge of this variation is accredited to André Broca and Sulzer.

The curves (fig. 1) which they have obtained[1] by comparing the brightness produced on a screen by a light of short duration, with a permanent light produced by a standard source show how various are the sensations occasioned by the time function for very different illuminations computed in lux[2]; they have for the first time, established with precision that, except for lights of very feeble intensity, the luminous sensation passes by a maximum at the end of a comparatively short time, and afterwards attains only slowly the constant value.[3]

These curves however, do not offer a solution of the problem which we are here considering, which is that of the limit of perception (that is to say at the threshold of the sensation) of feeble lights. Their intersections with the horizontal corresponding

* A short summary of this work was presented to the Academy of Science of Paris at its meeting on July 3rd, 1911.

1 Luminous Sensation in Time Function, *Journal de Physiologie et de Pathologie Générale*, No. 4, Juillet 1902.

2 1 lux = 1/10 millilumen per square centimeter; that is the illumination given by one candle at 1 meter (39.3 inches).

3 Helmholz, Brücke and Exner have already pointed out the existence of a maximum and have discovered that the time necessary for attaining it is shorter as the exciting luminous intensity is greater; but their methods have been subject to criticism; and Charpentier, who conducted analogous experiments did not find this maximum because he experimented with too feeble lights; moreover his apparatus did not show the observed screen at once.

to the threshold of sensation are not precise. Moreover (and this is an objection of principle) in the case of the threshold, the impression does not follow a curve, but appears suddenly with a value just perceptible when the action of the light has been sufficient in intensity and in time; otherwise there is no sensation at all.

A material comparison allows this important difference to be stated with precision; in Broca's and Sulzer's experiments, the eye seems to act very much like a galvanometer submitted to the action of a current during a part of the time of the oscillation

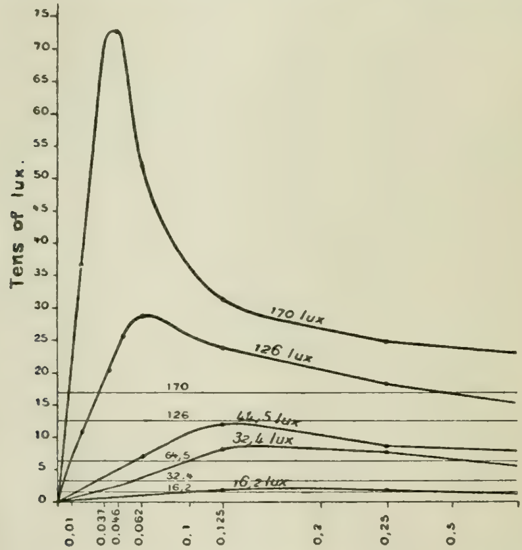


Fig. 1.—Broca's and Sulzer's curves, representing the variation of the luminous impression apparent in time function, for diverse illuminations of the screen under observation.

itself, the damping of which varies in inverse function of the effectual luminous intensity, for the sensation exceeds the normal working in a proportion so much the greater as the effectual luminous intensity is greater.

On the contrary, in the case here adduced, the luminous impression is briefer, or at the most as long as the period of its apparition on the threshold of sensation; the eye then acts like a ballistic galvanometer integrating the excitation. We have endeavored to find out the law of this integration in function of the

intensity of effectual luminous lighting and of its time of application.

This problem has been studied rather incompletely by different investigators. In 1834, Talbot[4] studied the law "Talbot-Plateau" on the persistency of the luminous impressions based on the well-known experiment of the rotating disk. He concluded that the sensation must be proportional to the time of the light's action. Swan[5] stated the same idea more clearly. The question, however, has only been treated with precision in the more recent works of Bloch[6] and Charpentier.[7]

Bloch contended that the excitation necessary for the production of the minimum sensation was perceptibly constant and proportional to the product of the illumination by the time Charpentier, who verified this law within certain limits, admitted that the retinal impression e produced by an illumination E of short duration t is fixed according to a linear law $e = Et$. As an immediate result it was seen that the luminous impressions produced on the retina by two sources of different intensity must be equal, if these sources are apparent during periods inversely proportional to the illumination they produce; hence Et is constant. Charpentier believed he had discovered that the law of the proportionality of the impressions to the time was true only up to the moment when the permanent sensation was attained; he had fixed this time for different luminous intensities (unfortunately all were considerably higher than the perceptible limit intensity) and had thus got figures varying between $1/8$ and $1/10$ of a second and seemingly proportional to $1/3$ or $1/4$ of the power of the absolute illumination. He admitted that all lights lasting a longer time were perceived integrally, as if they were permanent.

MacDougall[8] by a more improved method, had found it necessary to carry this period to $1/5$ of a second for feeble lights. Another investigator[9] had, from 1893, pointed out that the

[4] *Philosophical Magazine*, 1834, series 3, vol. V, page 327.

[5] *Transactions*. of the Royal Society of Edinburgh, 1849.

[6] *Comptes Rendus de la Société de Biologie*, 1885, series 8, vol. II, page 495.

[7] *Ibidem*, 1887, vol. II, page 5.

[8] *Journal of Psychology*, vol. I, part 2, June 1904, MacDougall has also pointed out the extraordinary rapidity with which the luminous sensation falls again after it has at tained its maximum, but without precisely stating the curve in a detailed manner.

[9] A. Blondel, *Flash-Lights and the Physiological Perception of Instantaneous Flashes*. (*Proc. of International Maritime Congress*, London, 1893, sect. IV, page 39.

discontinuity resulting from the sudden variation of inclination of the curve of sensation at the moment of integral perception cannot be admitted, for *natura non fecit angulos;* he therefore proposed to replace the straight line of sensation by a curve joining the horizontal at the same point. A better explanation of Charpentier's results can be found to-day in the curves of figure 1, the first part of which, starting from the origin rises as a matter of fact, perceptibly in a straight line as far as the horizontals of the permanent sensation; it is probable that Bloch and Charpentier believed that the curves stopped at these horizontals. As they are prolonged still higher Bloch's law loses all philosophical basis.

It is, moreover, contradicted by experience itself, as soon as one takes into consideration very feeble lights which are close to the limit of sensation: for then the time limit of addition is no longer found. Thus it is that, in the experiments of Broca and Sulzer, the time necessary for the permanent sensation varied between one second for strong lights to 2½ seconds for feeble lights, and that Ribière, experimenting by a different method and from a different point of view, discovered[10] that the limit range of a light of short duration increases almost indefinitely with the duration of the latter and always remains inferior to that given by the same intensity in the permanent state.

These facts have warranted our supposing that the product Et must increase in proportion as the intensity of the light draws near to the threshold of sensation and that Bloch's law can be applied only to intense and very short lights.

Moreover, it seems to us evident *a priori* that the time necessary for finding out in space the point where a point light source will just produce, when working normally, the threshold of sensation must be so great that practically the eye, while searching for this point, must never remain fixed upon it long enough to discover it.

We have therefore, been led to infer that the discontinuous law of Bloch and Charpentier must be displaced by a continuous law in which the time of perception of a light just capable of producing the threshold of sensation should be infinite.

[10] M. Ribière, *Light-houses and Marine Signals*, 1908, page 15.

If in rectangular co-ordinates a curve is traced having for its abscissas the times and for its ordinates the effectual illuminations E, Bloch's law $Et =$ constant, is represented by an equilateral hyperbole I having for its asymptotes the two axes of the co-ordinates; whereas the law sought should approach an equilateral hyperbole II which would have for its asymptote a more elevated horizontal $E = E_0$ (E_0 denoting the minimum illumination perceptible) and of which the equation would therefore be in the form:

$$(E - E_0)\, t = C^{te}.$$

Not wishing to stop at this theoretical induction, we have tried to find out by experiments the law of the relation between E and t (when they produce the limit sensation) while taking care to employ a great number of observers who were kept in ignorance of the result sought.

METHODS AND APPARATUSES EMPLOYED.

Our observations have had to do with lights of short duration from punctiform sources; that is to say produced by an artificial luminous source having dimensions which cannot be estimated by the naked eye; for it is under such conditions that signals are perceived at a great distance.

All our experiments have been made in the laboratory, in order to avoid all the disturbing influences which are to be met with in the open air, such as the variation of the atmospherical absorption, the effect of surrounding lights, the fatigue of the observers, etc. It is only in the laboratory that phenomena of this kind can be studied with precision in order to establish laws at least approximative.

In these conditions, it might be proposed either to compare the effect of a flash with that of a constant light just perceptible and serving as a standard of comparison, or to simply compare two lights, one of which is constant. Experience has shown us that the latter method is the better, for it alone allows of comparable impressions being obtained. Experience has proved to us, moreover, that the fatigue of the observers is much greater when a permanent light instead of a flash is taken as a basis of comparison. This results, we think, from the fact, that the limit

of perception is much less distinct when a person observes a permanently luminous point than a short flash.

Naturally, the flashes produced by the short lights, or lights of very short duration, must succeed each other at rather long intervals, so that there is no probability of the mutual influence of the two successive impressions.[11] That is why we have generally adopted a period of about three seconds between the successive appearances of the flashes.

This being granted, we experimented with the method of equalization, that is to say by trying to render equal two short flashes differing from each other by the values E and *t*. This equalization may be effected in two ways: either by examining alternately the two flashes each of them appearing separately, or on the contrary by examining them simultaneously. The first method has already been recommended by MacDougall[12] who, however, did not use it to equalize the flashes, but to determine the differences producing perceptible gradations of sensation. The second method was employed in 1893[13] by another investigator who caused a black disk provided with a radial slit of constant width to revolve in front of a black screen covered with small equal circles of white paper placed all along one radius.[14]

But this method seemed at that time to offer at least one inconvenience: the sensations did not appear simultaneously. In the present experiments it has been assumed that to obtain the necessary apparent simultaneity, it sufficed to make not only the luminous excitations begin at the same time but to end at the same time.

An apparatus which allows of this second method being carried out has been devised by M. Marsat, an engineer of the firm Sautter & Harlé. It has been used for most of the experiments, the results of which are given further on. Another apparatus which allows of one or the other two methods being

[11] This condition is still more necessary when one measures impressions above the impression limit, for then he has to fear consecutive accidental images, as Broca and Sulzer have shown.

[12] *Loc. cit.*

[13] A. Blondel, *loc. cit.*

[14] The distance from the axis of rotation to the centre of the first small circle presenting a weakened flash gave a measurement of the limit duration, which it was then believed, could be determined.

adopted as desired has been constructed from the plans of one of us and by M. Camillerapp, constructing engineer. We here give a brief description of both apparatuses:

Rey's Apparatus.—This is shown in figs. 2 and 3. A diagram of the device employed is shown in fig. 2. It comprises a luminous source S formed by an incandescent lamp made up of a two-branch filament in a U shape with the sides as nearly parallel as possible. The source really utilized is formed from a portion of one of the filament branches the length of which is limited by screens. This luminous line lights a small lens L_1 which is placed

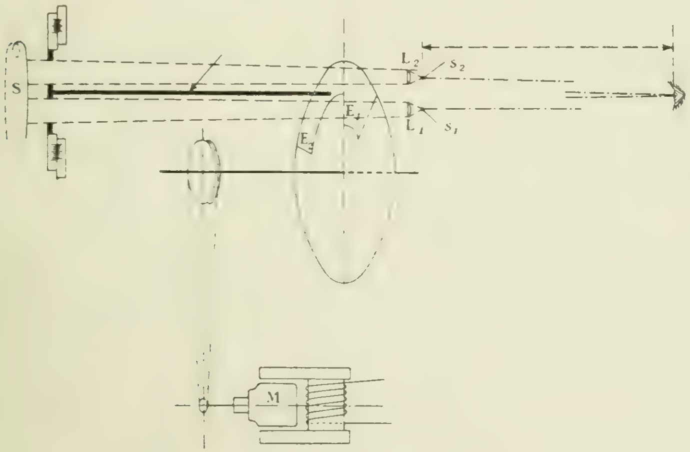


Fig. 2.—Diagrams of Rey's apparatus. S. is the filament of the incandescent lamp in front of which are placed two variable diaphragms; E_1, E_2 are variable angular openings in the revolving disk; L_1, L_2 are concentrating lenses; S_1, S_2 are aerial images produced by the lenses and serving as luminous points; and M is the motor.

at a distance of from about 16 to 32 inches (40 to 80 cm.). The image formed by this lens which has a focal length of only 8 millimeters (0.314 inch) constitutes a secondary source S_1, of dimensions small enough to enable it to be considered as a point source for the eye of the observer placed at a distance of from 17 feet 6 inches to 65 feet (6.333 m. to 19.812 m.).

A second lens L_2 is lighted by another portion of the filament branch of the source S, a portion the length of which may be lengthened as desired. The image given by the lens L_2 forms a second point source S_2, the intensity of which may be regulated

as desired, and which is proportional to the length of the luminous filament utilized.

Between the lenses L_1 and L_2 and the luminous source S, there is placed a system of rotating screens, formed by two disks, with angular openings, which have a common shaft and are driven at a constant speed by an electric motor M.

The whole system is equivalent to a single disk with two openings, one of fixed dimensions, and the other of variable width.

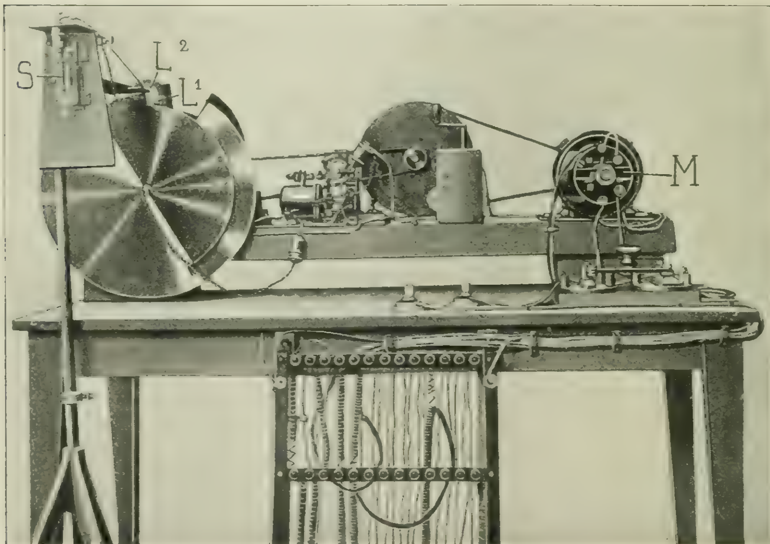


Fig. 3.—Photograph of Rey's apparatus.

One of the angular openings which has a fixed width E_1 passes in front of the lens L, and causes a flash of constant intensity and duration.

The other opening E_2 passes in front of the lens L_2 and causes a flash of a duration varying with the width of the opening, and of an intensity equally varying according to the length of the filament utilized. The openings are so placed that the two flashes are simultaneous.

The principle of the method of measuring is as follows: The observer compares the two flashes; first by coming near enough

to the apparatus to see them clearly. He then moves away until he sees only one. From his instructions the operator modifies the intensity of the source S_2 and the observer begins over again. On further instructions from him the source S_2 is again modified until he ceases to perceive the two flashes at the same distance away from the apparatus. The two flashes are then of equal visibility, that is to say they have the same range limit for the observer. At this moment the length utilized of the filament of the source S_2 is measured and recorded. The experiment has shown that, as soon as the observer draws near, the impression of equality ceases and the more rapid flash appears as the more intense.

In order that the observations may be correct it is indispensable that the intervals between two successive flashes should be the same for one and the other source and that their period should attain three seconds at the minimum.

With the aid of the mechanism described above and shown in fig. 3, it has been possible for us to produce flashes of any period, from the thousandth part of a second up to three seconds, that is to say varying in the extreme ratio of 1 to 3,000. The slight thickness of the filament of the source S, which is about one-tenth of a millimeter (0.00393 inch) and negligible when compared with the width of the slit which attains 6 millimeters (0.236 inch) at the minimum, permits of an almost instantaneous appearance and disappearance of the flashes, by reducing to quite an insignificant value the systematical error pointed out in a note with respect to Charpentier's method.

Blondel's Apparatus.—This apparatus is based upon the employment of diaphragm lenses introduced into photometry by Bougier, then by Cornu, and which has been considerably improved upon by the inventor[15]. Figures 4, 5, 6 show a diagram of the arrangement of the apparatus and figure 4*a* shows a section of it.

[15] Blondel has replaced the former cat's eye by a special one formed by two curtains which move parallel to each other; when they meet each other on contact with a rectangular diaphragm which has the total width for an opening and of which the height varies from one diaphragm to the other; this arrangement allows of the maximum sensibility of the graduation being obtained at the same time as the proportionality of the readings to the openings. Another improvement consisted in substituting the simple lenses of Bouguer-Cornu, which give deformed images, by a system of double achromatic lenses which allow of very slight focal lengths being obtained with a very slight aberration.

The apparatus comprises three photometric tubes T_1, T_2, T_3, each supplied with a cat's eye capable of being regulated O_1, O_2, O_3, the displacement of which is read on a small revolution counter placed in front.[16] At the entrance of each tube there is a diaphragm D_1, D_2, D_3, having in the center a hole of about 10 millimeters (0.393 inch) in diameter covered by a small screen of opaline glass.

Each of these screens is strongly lighted by a filament f_1 of a Nernst lamp N_1, mounted on a cylindrical support M adjusted to friction on the tube T_1; the intensity of the illumination can be made to vary to a certain extent by pressing more or less on the support M_1 or T_1; perforations made in the support and hidden on the outside by protecting screens allow of the cooling. The three Nernst lamps operated in multiple on a system at 110 volts.

The screen E_3 produces an image at the conjugate focus on a small circular orifice a_3, which itself is supplied with a screen of depolished glass a few millimeters in diameter; in the same way the screens E_1 and E_2 produce their images on the screens a_1 and a_2 after being reflected on the mirrors M_1 and M_2 at 45 degrees.

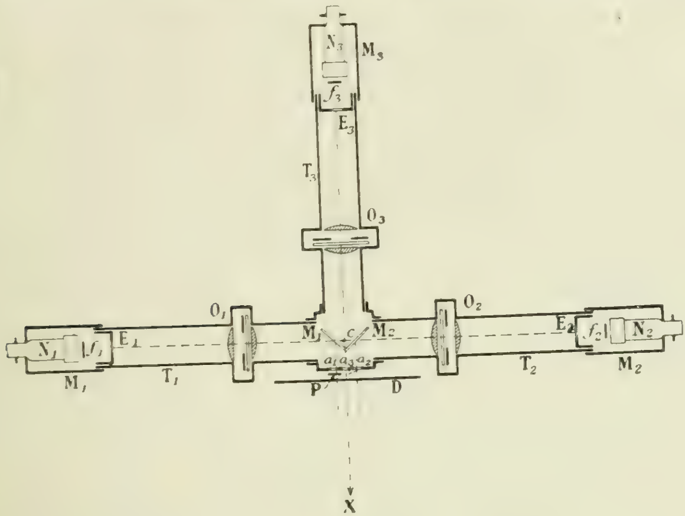
The tube T_3 being placed a little higher than the others, the three small depolished glasses a_1, a_2, a_3, appear as shown in fig. 5, at the apex of an equilateral triangle having a side of about 30 millimeters (1.181 in.) In front of each of these depolished glasses there is placed a small diaphragm (not shown), supplied with a small tube of 1 or 2 millimeters (0.039 to 0.078 in.) in diameter which allows of exact images being observed. The intensity of each of these luminous points can be made to vary as desired by working one of the three cat's eyes.

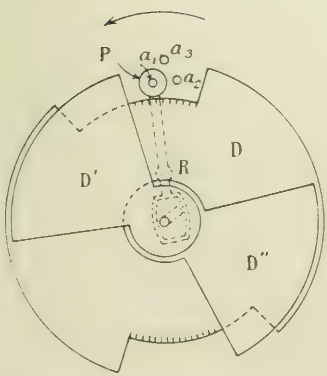
It is these three luminous points which the observer compares when standing in the direction X at a distance of from 6 feet 6 inches to 19 feet 6 inches (1.980 to 5.943 m.).

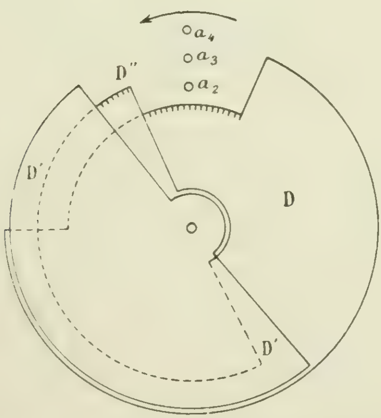
Between the observer and the luminous points there is placed an opaque disk D, which is driven at a speed of a few revolutions per second by an electric motor (not shown in the

[16] Figure 4 shows a horizontal section, supposing, in order to simplify matters, three tubes T_1, T_2 T_3, in one and the same plane. But, in reality, the tube T_3 has its axis raised 3 centimeters (1.181 in.) compared with that of the other two.

diagram), which causes certain of these points to be covered for a time which may vary. Figures 4 and 5 show two arrange-







Figs. 4, 5 and 6.—Diagrams of Blondel's apparatus. Fig. 4 a horizontal section of the whole apparatus. Fig. 5 the arrangement of the revolving disk with two openings capable of being regulated and the oscillating shutter P in relation with the three holes a_1, a_2, a_3, which serve to produce the luminous points. Fig. 6 another arrangement of the disk with variable apertures and the holes producing the luminous points.

ments which may be employed as desired for obtaining lights of short duration.

In the device shown in fig. 5, the disk D is provided with two

openings which can be regulated as desired by two independent sectors D′ and D″ (which are secured by clamp buttons not shown in the plan).

The disk D has a radius slightly less than the distance which separates its center from the small screen a_3, so that the luminous point produced by the Nernst lamp N_3 is always visible and can be used as a marker to direct the eye and even eventually as a point of comparison; the intensity of this marker is capable of being regulated, as a matter of fact, by the cat's eye O_3. An opaque shutter, P, actuated by an eccentric which gives it alternating movements about the axis of oscillation R, obscures alternately the screen a_1 and the screen a_3 respectively during the passages of one of the other of the two openings; so that the

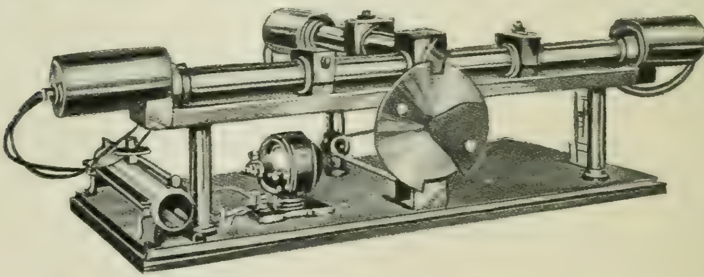


Fig. 4a.—Photograph of Blondel's apparatus.

observer sees alternately the flashes produced by a_1 and a_2, and which are regulated respectively by the widths of the two graduated openings. Thus the desideratum of psycho-physicists, which is to compare two flashes appearing alternately is obtained. Their duration is measured by the angles and the speed of the disk which is measured by means of a revolution counter and which is capable of being regulated by the rheostat of the motor. By acting on the cat's eyes O_1 and O_2 the apparent flashes are equalized.

In this way, the sensations of these intermittent flashes may be compared with those of the fixed point a_3[17].

[17] The arrangement in a triangle of the three luminous points allows of the flash on the right always being easily distinguished from that on the left; that is why we take two independent mirrors M_1 and M_2. In certain cases, however, these two mirrors can be replaced by a single one passing through the centre of symmetry C of the apparatus and the oscillating plate P by another eccentric control, which alternately displaces the common mirror so that it alternately reflects on one and the same opening placed below a_3 the rays coming from E_1 and those emanating from E_2.

The device shown by fig. 6 also allows of simultaneous flashes being obtained as in Rey's apparatus. In this case the two holes a_1, a_2 are displaced by a single one which is lighted by a mirror placed at the point of symmetry C. The other hole a_3 is lighted by the screen E_3: above the central box of the apparatus there is another small hole for a marking point a_3, lighted by a small supplementary incandescent lamp and which simply serves to fix the direction. The two sectors D and D′ serve to regulate the widths of the two openings situated at different distances from the center so as to give to the flashes of a_2, a_3 different durations terminating at the same moment.

Thanks to the very small dimensions of the luminous points that the duration of the flashes can be regulated with great precision. The apparatus lends itself to the most varied combinations.

DISCUSSIONS AND CALCULATION OF THE RESULTS OBTAINED BY THE EXPERIMENTS.

The experiments of the results of which we purpose to give a summary, were carried out for the most part in the laboratory of the firm of Sautter, Harlé & Co., by means of the first apparatus, with the collaboration of a former student of the Polytechnical School, Mr. George Guy, who directed the observers and aided us in the calculations; furthermore, the experiments were checked by Mr. Blondel, in his own laboratory, with the second apparatus.

Measurements.—The observations comprised twenty-five series made by seventeen observers of different ages and occupations—workmen, engineers, foremen, clerks, and others. These observers naturally had very different keenness of sight: some were short sighted, others long-sighted, others again were afflicted with astigmatism; in a word, it may be said, that all the degrees of usual sight were represented.

It was possible to draw a comparison between these different sights by taking as a standard for each observer a measurement

made by himself under definite conditions and consequently by considering only relative values.[18]

TABLE I.

Numbers of the measurements	$t = 0.03$ sec.				$t = 0.10$ sec.			
	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$	d	d^2
1	16.4	1.274	0.148	0.0219	8.0	1.062	0.047	0.0022
2	18.0	1.067	*—0.059*	35	7.0	0.954	—0.061	37
3	20.0	1.217	*0.091*	83	10.4	0.978	—0.037	14
4	6.0	1.176	0.050	25	3.6	0.875	—0.140	196
5	16.7	1.180	0.054	29	4.0	1.278	0.263	692
6	12.0	1.263	0.137	187	5.3	1.095	*0.080*	64
7	13.0	0.947	—0.179	320	4.24	0.911	—0.104	108
8	10.7	1.104	—0.022	5	4.9	0.920	*—0 095*	90
Totals ...		9.228	0.740	0.0903		8.073	0.827	0.1223
Averages		1.153	0 0925	0.1062		1.009	0.1034	0.1236

Numbers of the measurements	$t = 0.30$ sec.				$t = 1.00$ sec.				$t = 3.00$ sec.	
	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$
1	3.7	0.920	0.121	0.0146	3.4	0.434	0.010	0.0001	3.08	0
2	3.8	0.742	*—0.057*	32	3.0	0.322	—0.102	104	2.1	0
3	5.4	0.786	0.013	2	3.5	0 451	0.027	7	3.3	0
4	1.7	0.724	*—0.075*	56	1.2	0.352	*—0.072*	52	0.9	0
5	2.7	0.972	0.173	299	2.1	0.558	0.134	180	2.53	0
6	3.1	0.851	0.052	27	2.0	0.518	0.094	88	2.2	0
7	2.24	0.711	—0.088	77	1.34	0.411	—0.013	2	1.15	0
8	2.36	0.761	—0.038	14	1.67	0.388	*—0.036*	13	1.36	0
Total.		6.467	0.617	0.0653		3.434	0.488	0.0447		0
Av's.		0.808	0.0772	0.0904		0.429	0.061	0.0747		0

[18] As all our measurements refer really to a standard which varies according to the observer, and which is the minimum perceived by this observer, we have not expressed this law in absolute photometric units. It is, moreover, easy to form an idea of the average order of magnitude of these measurements by remarking that, according to the old determinations of Léonce Reynaud and Allard, the minimum illumination perceptible from a point source is considerably less than the practical figure 10^{-7} lux (an illumination produced at 1 kilometer (0.621 mi.) by 1/10 of an international candle); the average value is close to 0.50 to 0.60 $\times$ 10^{-7} when the operator is in the laboratory protected from all stray light. The figure of 10^{-7} is nearer the normal conditions for observation in the open air.

The apparatus which we have described permits easy standardization of the intensity of the luminous points employed; it suffices to standardize the most powerful ones by causing them to illuminate, at a known short distance, the screen of a photometer, the other face of which is illuminated by a standard equal to an international candle.

This amounts to estimating for each observer the luminous intensities as a function of the minimum intensity perceptible by the same observer.

Besides, as it is extremely difficult to make a direct comparison of very long flashes with very short ones, we worked by successive comparisons; in particular, short flashes of less than a second have been compared with flashes of 0.03 or 0.3 of a second; those of one second were then compared with longer flashes capable of attaining three seconds. A summary of the results of the readings is given in the accompanying two tables.

The first eight series (first table) refer to measurements worked out on flashes, of varying duration from $^3/_{100}$ up to three seconds. The seventeen other series (second table) deal with flashes, the duration of which varies from $^1/_{1000}$ up to $^3/_{100}$ of a second.

The different points of observation correspond to eight different periods which are the following:

0.001 ; 0.003 ; 0.01 ; 0.03 ; 0.1 ; 0.3 ; 1 ; 3

Calculations.—Notwithstanding all the precautions taken, the readings vary in such rather large limits that we did not seem justified in deducing arithmetical averages: it is, therefore, expedient, according to the principles of the calculus of probabilities, to have recourse rather to geometrical averages. These are easily obtained by introducing, instead of the figures themselves, their logarithms, for the average of the logarithms of several numbers is the logarithm of the geometrical average of these numbers.[19]

In the two tables, the first column gives the number of the observation. The second column indicates the *relative* intensity E of the source S_2 reckoned in millimeters of length of filament utilized. The third column gives the value of the logarithm of the quotient of Et divided by the value of Et corresponding to the point of three seconds taken as a term of comparison. The

[19] In all that follows, we have compared the product Et with the corresponding products obtained for a duration of 3 seconds

It must not be concluded that we attach great importance to this latter reading, which is most uncertain; we simply wished to convert everything into relative values and we have chosen 3 seconds only because it was the extreme point of our observations; in reality, these latter are of practical use only between 0 and 1 second, for in all modern signals, instantaneous flashes exceeding or even attaining the second are not employed.

TABLE II.

Numbers of the measurements	$t = 0.001$				$t = 0.003$				$t = 0.01$				$t = 0.03$	
	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$	d	d^2	E	$-\log \frac{Et}{3E_3}$
1	40	1.232	0.050	0.0025	12.4	1.263	0.085	0.0072	5.0	1.136	—0.028	0.0008	1.60	1.153
2	40	1.324	0.142	202	14.3	1.294	*0.116*	134	4.9	1.236	—*0.072*	52	1.98	—
3	40	1.350	0.168	282	—	—	—	—	5.7	1.196	0.032	10	2.1	—
4	40	1.070	—0.112	125	8.4	1.270	0.092	85	3.0	1.194	0.030	9	1.1	—
5	40	1.329	0.147	216	26.0	1.039	—0.139	193	7.0	1.086	—0.078	61	2.0	—
6	40	1.174	—0.008	1	17.0	1.069	—*0.109*	119	7.0	0.931	—0.233	543	1.4	—
7	40	1.204	0.022	5	19.3	1.044	—0.134	180	5.6	1.058	—0.106	112	1.5	—
8	40	1.108	0.074	55	7.5	1.357	0.179	320	2.5	1.311	0.147	216	1.2	—
9	40	1.174	—0.008	0	18.4	1.035	—0.143	204	4.9	1.086	—0.078	61	1.4	—
10	40	1.174	—0.008	1	17.0	1.069	—0.109	119	4.6	1.114	—0.050	25	1.4	—
11	40	1.174	0.008	1	19.8	1.003	—0.175	306	5.3	1.052	—0.112	125	1.4	—
12	40	1.142	—*0.040*	16	8.5	1.338	0.160	256	2.1	1.421	0.257	661	1.3	—
13	40	1.028	—0.154	237	10.0	1.153	—0.025	6	2.5	1.232	0.068	46	1.0	—
14	40	1.174	—0.008	0	21.8	0.961	—0.217	471	4.3	1.143	—0.021	4	1.4	—
15	40	1.159	0.023	5	14.0	1.137	0.041	17	4.25	1.132	—0.032	10	1.35	—
16	40	1.174	0.008	1	17.0	1.069	—0.109	119	2.5	1.368	0.204	416	1.4	—
17	40	1.283	0.101	102	17.0	1.178	0.0	0	5.0	1.186	0.022	5	1.8	
Total		20.273	1.081	0.1274		18.279	1.833	0.2601		19.888	1.570	0.2364		
Averages..		1.193	0.0635	0.0866		1.142	0.1145	0.1275		1.1695	0.0923	0.1180		1.153

fourth column gives the difference between the logarithmic value of the observation (preceding column) and that calculated by the general law which we have deduced from the whole and which we show in table III. The fifth column gives the square of this difference. We have drawn particular attention in the fourth column to the probable difference, defined by the well-known condition that, in the series of observations for the duration considered, there should be as many differences greater than as there are differences less than the probable divergence.

At the foot of each column are shown the totals and the averages of the values included in the said columns. The average of the third column is the logarithm of the geometrical average.

TABLE III.

t Sec.	(Et) geometrical averages	$\frac{t-0.21}{3.21}$	Difference	$-\log\frac{t-0.21}{3.21}$	η	$\frac{e}{1.2}$	$\frac{2}{3}\epsilon_1$
3.00	1	1	0	0	—	—	—
1.00	0.372	0.377	—0.005	0.424	0.054	0.051	0.050
0.30	0.1555	0.1588	—0.0033	0.799	0.066	0.064	0.060
0.10	0.1021	0.0965	+0.0056	1.015	0.087	0.085	0.082
0.03	0.0703	0.0748	—0.0045	1.126	0.075	0.077	0.071
0.01	0.0677	0.0685	—0.0008	1.164	0.072	0.077	0.079
0.003	0.0721	0.0664	+0.0057	1.178	0.112	0.095	0.085
0.001	0.0641	0.0657	—0.0016	1.182	0.040	0.053	0.058

The average figure of the fourth column represents what is called the mean difference, that is to say the arithmetical average of the deviations disregarding signs.

The average for the fifth column is the mean square difference.

From these tables we have deduced in fig. 7 a curve graphically showing the results of the observations. In this curve, the abscissas represent the duration of the flashes in seconds, the units chosen in our calculations; the ordinates, the value of the product Et (that is to say the product of the illumination by its duration) divided by the value of the same product in the case when the flash lasts three seconds.[20]

It is most remarkable to notice that the mean values of the observations for each of the eight durations of flash considered fall almost exactly on a straight line. This result, as will be

[20] E is here expressed only in arbitrary or relative units and not in lux. But this in no way affects the result.

seen, does not imply exceptional precision, but it is rather the result of a happy chance. It is, however, interesting to have obtained such a good alignment for observations carried out between such great limits of duration; the result obtained for three seconds is not, we think, of great value, but the linear law seems to be seriously verified between 0 and 1 second, that is to say within the practical limits of use.

Precision.—We have thought it useful, in any case, to find out the degree of precision of the experiments, and table III gives a summary of the calculations made with this object in view.

The first column of the table gives the times in seconds.

The second column contains the geometrical mean value E*t*

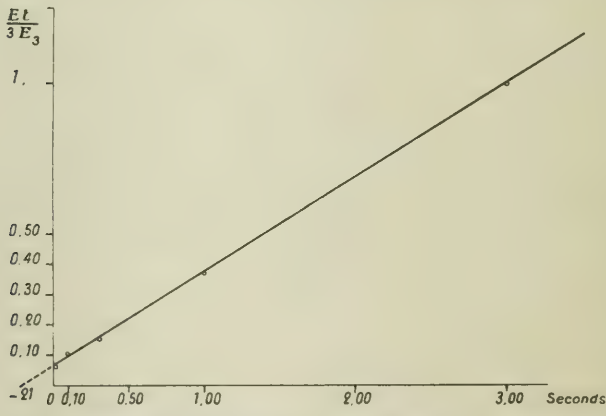


Fig. 7.—Curve representing law of variation of the product E*t* in terms of the time *t*, as deduced from the results of the experiments.

of all the observations, and for each point observed; it is the number of the average logarithm calculated at the foot of the tables I and II, third column.

The third column gives the value of average E*t* calculated after the straight line fig. 6 deduced from the average of the observations.

The fourth column is the difference of the two results.

The fifth column gives the logarithm of the values of the third column; it is this that has served as a basis for calculating the differences *d* recorded in the first two tables.

The sixth column gives the probable difference defined as we have already stated.

The seventh column gives the average difference divided by 1.2, the mean difference being defined as before.

The eighth column represents two-thirds of the mean square difference.

According to the general theory of probabilities, the numbers recorded in columns 6, 7 and 8 should obviously be sensibly of the same order of magnitude and represent the probable error of the logarithm of the results; this logarithmic error is here comprised between 0.05 and 0.10, and from this one deduces that the probable relative error of the results is comprised between 12 and 25 per cent. In such a delicate question as physiological optics and considering the very different eyes of the observers, these limits of errors[21] are very acceptable, and it may be considered that the linear law represented by fig. 7 has been satisfactorily established.

Numerical expression of the law.—The straight line in fig. 7 shows that the product Et is a linear function of the time, $Et = A + Bt$, by calling E the intensity of illumination received on the pupil and supposed to be constant during the whole period of the flash, A and B two constants.

In order to determine these constants, we may remark that when the flash lasts indefinitely ($t = \infty$), the intensity perceived at the limit of the range is exactly equal to the threshold of the perception, corresponding to the perceptible minimum illumination E_0; whence $B = E_0$. On the other hand, the representative straight line of Et cuts the axis of the abscissas at a distance representing $^{21}/_{100}$ of a second on the left of the origin, whence we obtain $A = 0.21\ E_0$ or more generally speaking $A = aE_0$ by calling a a constant of time.

[21] A great many of the irregularities in the measurements must be attributed to the variations of the state of adaptation of the observers. In order to operate theoretically in a faultless manner it would have been desirable to eliminate all variations of the opening of the pupil by placing before the eye of each observer an artificial pupil 2 millimeters or 2.5mm. (0.078 in. or 0.098 in.) in diameter; but we hesitated to adopt this complicated arrangement, because most of the operators were wanting in the training necessary for making use of it; besides we should have thus strayed too far from the conditions in practice surrounding the observers looking at direction signals.

We have therefore finally:

(1) $$Et = E_0\,(0.21 + t) = E_0\,(a + t),$$

which may be written also:

(2) $$(E - E_0)\,t = 0.21\,E_0,$$

an equation which is of the order we had *a priori*[22] foreseen.

The same numerical law may be expressed under still another form:

(3) $$\frac{E}{E_0} = \frac{0.21 + t}{t} = 1 + \frac{0.21}{t},$$

or again:

(4) $$t = \frac{0.21\,E_0}{E - E_0}.$$

These different methods of expression may be employed according to the applications to be made.

For all these formulas it is supposed that the observer is standing at the range limit of a light with regular flashes, the coefficient of atmospherical transparency being supposed to be unvarying during the whole experiment.

A Permanent Light Equivalent to a Short Light.—Suppose that a permanent source is substituted for a light of quick flashes, placing it at the same point, and that the intensity of this permanent source is regulated so that the observer still perceives it at the same range limit, that is to say without changing position, the preceding law gives the ratio between the horizontal photometric intensity I_h of the rapidly flashing light and the intensity I_h of the fixed light which has been substituted for it. Since the period of the flash is supposed to be known, it is seen by (3) that the apparent intensity of the light which produces the flashes is reduced in the proportion of:

$$\frac{t}{a + t}.$$

A fixed light I′ would therefore suffice such as

(5) $$\frac{I'_h}{I_h} = \frac{a + t}{t}.$$

[22] Other experimenters may perhaps find that the constant 0.21 needs to be corrected and that the constant E_0 is perhaps slightly different from the illumination which corresponds to the threshold of sensation; but that would not prevent the formula from preserving the same more general form:

$$(E - b\,E_0)\,t = a\,E_0,$$

a and *b* being two constants.

Comparison of the New Law and of Bloch's Law.—If on two rectangular axes (fig. 8) we place as abscissas the times t and as ordinates the illuminations E, the formula (1) is interpreted by an equilateral hyperbola (II) having for asymptotes the axis of the E's and a horizontal $E = E_0$.

Bloch's law requiring for very short times of exposure sensibly the same values of E, will have for an equation $\frac{E'}{E_0} = \frac{0.21}{t}$ and will be represented by an equilateral hyperbola (I) capable of being superposed, but lowered entirely through a height E_0.

Table IV indicates the ratio of the ordinates $\frac{E}{E'}$ and shows clearly in what proportion the intensities must be increased ac-

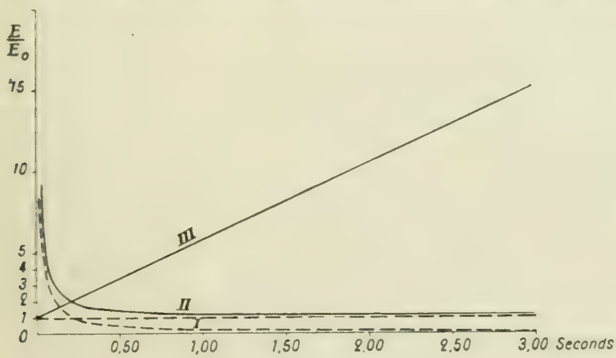


Fig. 8.—A graphic comparison of the new law with Block's law.

cording to our law, compared with what would have been required, for the same durations of flash if Bloch's law were supposed to hold.

For very short durations such as for the hundredth part of a second, the difference is negligible; they already attain about 50 per cent. for a flash duration of one-tenth of a second and increase even much more for longer durations.

The curve (III) graphically represents the variation of this ratio. If it is only remarked that in the greater part of existing modern signals of orientation, the flashes last longer than one-tenth of a second, it will be understood how opportune it is to

TABLE IV.

Period t Sec.	I Bloch's law $\frac{E'}{E_0} = \frac{0.21}{t}$	II New law $\frac{E}{E_0} = \frac{0.21}{t} + 1$	III Ratio $\frac{E}{E'}$
0.01	21.00	22.00	1.047
0.025	8.40	9.40	1.12
0.05	4.20	5.20	1.24
0.10	2.10	3.10	1.40
0.20	1.05	2.05	1.95
0.30	0.70	1.70	2.43
0.40	0.525	1.525	2.90
0.50	0.42	1.42	3.40
0.60	0.35	1.35	3.86
0.70	0.30	1.30	4.33
0.80	0.2625	1.2625	4.81
1.00	0.21	1.21	5.76
2.00	0.105	1.105	10.52
3.00	0.07	1.07	12.95

substitute for Bloch's law the more accurate law which we have established.

APPLICATION TO SIGNALS.

The new law offers a particular interest by reason of the important application which may be made of it in the technics of flash signals. These signals are of two kinds:

(1) Telecommunication signals, which are intended to telegraph, in an optical form, by means of short or long flashes, the letters of the Morse alphabet; (2) orientation signals, by which an observer can direct his sight towards a signal light or to take the bearings of its direction.

Telecommunication Signals.—In the case of optical telegraphy signals, the source of light employed giving out a continuous flux during the whole time that it is in use, no economy of lighting is obtained by reducing in a greater or lesser degree the duration of the signals[23]; this duration can therefore be regulated solely according to the best working conditions for the observers. Now according to André Broca,[24] there are two limits to be observed for this kind of signals:

First of all, a sufficient time (which varies from one-one

[23] It would be otherwise if, for producing these signals, an incandescent lamp with metallic filament were used, distributing the current only while the signal is being sent, or a gas burner alternately lighted and extinguished.

[24] *Annales du Conservatoire des Arts et Metiers*, Conference held on Sunday, January 26, 1902.

hundredth of a second for very strong lights to two-tenths or three-tenths of a second for feeble lights) must be allowed between the signals, so that the luminous sensation may become somewhat less intense between two signals in order to avoid the persistency and consequently allow of their being distinguished.

On the other hand, the signals should be of a duration sufficient for good perception, viz.: at least two-tenths of a second for short distances and from five-tenths to six-tenths of a second for long distances.

The same author contends, moreover, as the result of his experiments mentioned above, that intense or too short lights (shorter, for instance, than one-tenth of a second) cause accidental images, in consequence of fatigue, because they do not allow the retinal reflexes time to act; the minimum period of the shortest signal in a good light should not be less than three-tenths of a second. The fear of an accident image, however, we believe may be eliminated by requiring the telegraph operators to wear slightly smoked spectacles when they have to receive messages from too short distances. Better still, the observers may be supplied with a glass equipped with an adjustable diaphragm which will allow them eventually to reduce the flash to the best intensity in function of its period; this, it seems, would be a more logical proceeding for avoiding the fatigue of a flash than to lengthen its duration to the detriment of the speed of the telegraphic output.

Orientation Signals.—In the case of orientation signals, there is no necessity for troubling about the period of persistency, because the interval obtained between the signals by the operations of concentration are always of quite considerable importance; practically it is never less than two seconds; even if it is reduced to one second, this eclipse is much longer than is necessary to avoid persistence.

Neither is it necessary to worry about accidental images, since the observer looks at the signal only when he desires to take bearings, an operation which, as will be seen further on, demands but a very short time. The only condition to be carried out is to increase as much as possible the useful range of the signals. It is precisely for this object that instead of a permanent light

intermittent signals are produced by using revolving searchlights.[25] The latter, concentrating in space the total flux of the source of light into a certain number of beams, which the rotatory movement throws upon the observer's eye, produce from a point of view of the utilization of luminous energy, an effect equivalent to that of an accumulator system which stores up during the period of the eclipses the luminous flux produced continuously by the source of light, and releasing it only in spurts.

From a photometrical point of view, the total flux emitted by the source should not be taken into consideration, but only that part of it which is received by the pupil of the observer, and which will be estimated by multiplying by the opening of the pupil the number of lux-seconds of excitation which it undergoes while the flash lasts. This calculation may be made in the following manner: Supposing that the source utilized in the optic apparatus has in its useful part the form of a cylinder with a diameter D and a uniform intrinsic brightness i,[26] the optical apparatus produces, besides the concentration of the flux in beams in the plane of the horizon, a vertical concentration proportional to the useful height[27] of its radiant surface h. If the light were uniformly distributed around the horizon the apparatus would produce a mean horizontal photometric intensity

$$I_{mh} - khDi,$$

and the illumination received on the pupil of the observer would be represented by a corresponding term:

$$E_{mh} = I_{mh} f(x) = khiDf(x) \tag{6}$$

calling k a co-efficient of diminution representing the losses sustained by the rays when passing through the apparatus, x the distance from the observer and $f(x)$ the function of diminution with the distance. This function takes theoretically the form of

$$\frac{b^x}{x^2},$$

calling b the co-efficient of the transparency of the atmosphere.

25 An invention of the illustrious Fresnel, improved by Bourdelles, who invented the apparatus with instantaneous flashes.

26 These hypotheses are somewhat theoretical and are not exactly obtained in practice, but they are of great use in stating precisely the opinion which we have here set forth.

27 That is to say the height of the exterior surfaces from which light is radiated.

On the other hand, the concentration produced in the horizontal plane by the optical apparatus resulting in the production of a flash at certain intervals, for instance at every T seconds only, the "quantity of illumination"[28] L received by the pupil during the flash is the result of the accumulation during T seconds and is expressed thus:

$$\text{(7)} \qquad L = E_{mh}T = khDiTf(x).$$

This quantity is proportional to the excitation of the retina and can be taken as a measure of this excitation.

Among the quantities which figure in this formula, $f\ (x)$ is unknown; the others are according to the different cases, the data of the problem to be solved: if the apparatus is constructed h and k are given; if the source is chosen, i and D are given. As for the interval T between the flashes, that has been fixed by considerations generally foreign to the question of the range.[29]

The only variable that remains and of which we must try to find out the influence is the period t during which the flash is produced. As a matter of fact, in consequence of the ease with which the construction and the rotatory speed of the apparatus can be varied, one is able to change in large proportions the time during which the beam passes in front of the pupil while always maintaining between the two signals the same interval, and giving to each of them a constant number of lux-seconds Et. The beam is supposed to be homogeneous. It is easily shown[30] that the period of the flash t is expressed in function of the interval of the flashes T, of the diameter of the source D, of the focal

[28] In photometry "quantity of light" is often called the product of the luminous flux by the time during which it is received. Similarly we shall call "quantity of illumination" the product of the illumination by the time.

[29] Experience has shown that, in order to take the bearings of the point whence the signals are emitted, the observer must not turn away his eyes, and that this result can be attained only if the interval between the flashes remains about five seconds; the tests which we shall cite further on have shown that, below this limiting magnitude, the bearings can be taken the more rapidly as the closer the signals are together; but it requires only a nearly constant number of signals received by the eye. It would be desirable, in order to facilitate the maintenance of the attention not to exceed an interval of two or three seconds between them, but in this way the period of the accumulation and, consequently, the quantity of light available in each flash, is reduced. We therefore find ourselves confronted by two desiderata which are opposed to each other, the better of which may be chosen according to circumstances. They are best brought into harmony, for instance, by means of certain groupings of flashes.

[30] Cf. Blondel *International Maritime Congress* 1893, page 46.

length of the optical apparatus R and of the number of beams n of the latter by,

$$(8) \qquad t = \frac{nTD}{2\pi R}.$$

After what has been stated, it is proper to draw a distinction first of all between two cases, according to which is given the optical apparatus or the source.

First Problem: *Given an existing optical apparatus allowing of the total flux of light being subdivided into rapid concentrated flashes every T seconds, what is the source of light which will permit the maximum output to be derived from this apparatus?*

It is very evident that it is the most powerful source of light, without, correctly speaking, giving any limit to its power. If, therefore, the source of light has an intrinsic brilliancy i, given in advance, and which may not be exceeded, its diameter D must be increased so as to increase to the utmost the period of each flash (which is proportional to this diameter); the illumination received by the eye will increase in the same proportion. In this way the only drawback is the excessive expense necessitated by the use of very powerful sources of light, and by the reduction of the specific output itself; for, for certain sources of light, such as the Auer mantels, the increase of volume is accompanied by a diminution of the intrinsic brilliancy.

On the contrary, any increase of the diameter of a source of light obtained without an increase of the flux (by interposing, for instance, diffusing glasses) not resulting in an increase of the flux of light, but only in the time of the excitation at the expense of its intensity would be prejudicial to the efficiency of the optical apparatus.

As a matter of fact, the limit impression, at a great distance, depending on the product:

$$(E - E_0)\, t = Et - E_0 t = L - E_0 t,$$

where L and E_0 are constants, it is seen that the impression is weakened in the same proportion as t increases. It is therefore of interest to reduce if possible the dimensions of the light source

producing a given flux, by increasing the intrinsic brilliancy i at the expense of the diameter D.[31]

Second Problem: *Given a source of light and the interval* T *between the flashes into which its total flux must be concentrated, what is the most advantageous flash period that can be obtained by the optical apparatus in order to acquire the maximum output of the said source of light?*

This is a problem to which the constructor of the optical apparatus must set himself, in order to know if it is more advantageous to increase or to reduce the duration of the flashes. The quantity of illumination $L = Et$ lux-seconds available for the flash being constant, and proportional to the total flux distributed on the horizon divided by the number of flashes; the argument used above at the end of the first problem proves that the efficient result at a great distance for the minimum perception will be so much the weaker as the duration of the flash is prolonged; the flux should be concentrated in the shortest time possible without there being any limit less than this period of concentration.[32]

Another important advantage which was placed in evidence in 1893[33] is that the shorter the signals the more rapidly does

[31] The remark on page 20 (formula 5) shows that the advantage is much greater by increasing the intrinsic brilliancy of a source, for instance in the ratio m, than by increasing the period in the same proportion m; for the multiplication of the period by m increases the apparent intensity of an equivalent fixed light in the ratio:

$$\frac{mt}{0.21 + mt} : \frac{t}{0.21 - t} = \frac{m\,(0.21 - t)}{0.21 - mt}$$

an expression which tends the more towards unity as t is larger; whereas if the intrinsic brilliancy of the source is multiplied by m the intensity of the equivalent fixed light is increased in the same proportion m; for instance, if $m = 2$, the intensity of a light at a great distance will be doubled. On the contrary if the diameter is doubled and consequently the period of a light having previously a duration of 0.21 for instance, the apparent intensity will be increased only in the proportion of $\frac{2}{3} : \frac{1}{2} = \frac{4}{3}$, so that the increase will be only 33 per cent. instead of 100 per cent.

In certain apparatus, the accumulation of light is replaced by an accumulation of compressed gas; the conclusion remains the same; the absolute intensity and the consumption of the burner must be increased at the expense of the period during which the burner is lighted.

[32] Formula 8 shows that there are two ways of effecting this concentration. On the one hand, increase the focal length R of the apparatus, which results in the concentration of the flash into a smaller angle (inversely proportional to the focal length); on the other hand, reduce the number n of beams of the optical apparatus and increase their rotatory speed or the number of revolutions per second N, in inverse proportion, so as to re-establish the same number of flashes per second, $t = Nn$, which is prescribed.

[33] *Loc. cit.*

their visibility increase when the observer, starting from the range limit draws near the point of emission.

As a matter of fact, the luminous impression increases more quickly when the light begins to act than after a certain time. It is therefore advantageous that the period of perception should be comprised in the part of the curves of the sensations adjacent to the origin and almost rectilineal, rather than in the curved part by which the sensation approaches the horizontal line.

This argument is confirmed *a fortiori* by the shape of the curves of Broca and Sulzer (fig. 1) which, for strong lights, rise at first well above the permanent sensation.[34]

There is also perhaps an advantage in reducing the time for another reason which has been pointed out to us by Mr. George Guy; it is in order to prevent the retina from moving while the flash is passing so that the image of the luminous point accumulates its excitation on one and the same point of the retina; otherwise it does not reach at any point of the latter its maximum of efficient effect.

In a word, it is always advantageous to reduce the duration of the flashes without the necessity of fixing a limit of minimum duration; the limit is, in reality, fixed by the conditions for producing the source of light and the apparatus.

Third Problem.— *Given the number of flashes per second, make the best apparatus and the best source of light for producing signals.*

This problem which is more general than the two preceding ones is, in reality, a purely economic problem similar to that formerly solved by Lord Kelvin for the most economical transmission of electric energy. We should endeavor to reduce to their minimum the annual expenses which are necessary for obtaining the desired end.

These annual expenses comprise, on the one hand, the amortization and the interest of the capital involved in the apparatus for the production of the light source (these are comparatively small); on the other hand the lighting expenses, that is to say, those which correspond to the consumption of energy and to

[34] It suffices to take, on the curve of a feeble light, corresponding to a flash E, the point of apparent impression corresponding to any period whatever t, then to find the point corresponding to the period n on the curve of illumination n E in order to see that the apparent impression is greater in the second case than in the first.

the up-keep of the light source and which are a function of the annual number of hours B during which it is in use.

If we call A the capital invested, f the rate of interest and amortization, p the cost of lighting per hour we must endeavor to obtain the minimum sum of $Af + Bp$, while at the same time satisfying the equation of condition:

$$\text{(9)} \qquad Et = E_0 \, (a - t).$$

By substituting for E its expression calculated above, the more explicit condition is obtained:

$$\text{(10)} \qquad E_0(a - t) - E_{mi}T = khDiTf(x)$$

or according to (8):

$$\text{(11)} \qquad E_0 \left(a - \frac{nTD}{2\pi R}\right) - khDiTf(x) = k'RDiTf(x);$$

remarking that h is generally proportional to the focal length R of the optical apparatus

The price of the apparatus increases in direct proportion of R^2 and varies considerably according to the mode of construction.

It is seen that the problem is too complicated to be solved by algebra. Moreover, the different sources of light (petroleum, gas, incandescence, electric arc, etc.), which may be employed are very dissimilar in their characteristic qualities D, i, and in their consumption. Their net cost is very varied.

The problem, therefore, generally speaking can only be solved by successively comparing several concrete solutions which have been previously studied from a technical point of view, which is quite apart from this study. It is simply sufficient for us to point out that this problem exists, and that one of the essential elements of the solution is supplied by the conditional equation which we have just indicated.

A case in which the flash has not a constant photometric intensity during its period. All the preceding deductions have been made to simplify matters in the theoretical case of a flash preserving a constant intensity during the whole of its period of application on the eye; but, in practise, this condition is never obtained. In particular, the optical apparatus intended for the accumulation of the light produce only imperfectly homogeneous beams, so that, while a flash is passing, the illumination pro-

duced on the eye starts from zero, increases rapidly, remains more or less constant for a certain time and then diminishes; and the variation follows a rather arbitrary law, being dependent on the sources and the apparatus.

In this case the problem becomes too complicated to be treated by the methods already previously given, in perception at a short distance, that is when the intensity of the sensation goes beyond the threshold; but when it is simply a question of determining the signal range corresponding to the threshold of sensation, the new law which we have established gives, by a permissible extrapolation, an easy solution. As a matter of fact, as we have previously stated, the eye acts a kind of ballistic apparatus. It

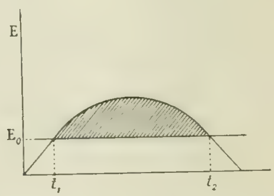


Fig. 9.—Graphic representation of the calculation by an integral of the useful luminous excitation when the photometric intensity in the flash of light is not constant during the time of the flash.

therefore suffices to take into consideration the integral of the excitation of the pupil while the flash or beam is passing.

Now, we have shown that the useful excitation is at each moment, proportional to the difference $E-E_0$ between the real illumination E and the limiting illumination E_0 of the threshold (fig. 9). If ye call t_1 and t_2 the moments when E becomes equal to E_0 at the beginning and at the end of the flash, the integral of excitation can be obtained by the simple quadrature of the curve representing E by measuring with the planimeter the area of this curve which is placed above the straight line E_0[35]. If this quadrature is made at any distance whatever, there will be found an area greater than the value $a\ E_0$, which according to the equation (1) corresponds to the perception; from which it will be

[35] It must be well understood that we accept this integration only for flashes, of short duration such as are employed in actual practice, that is to say lasting at most a second; we have not sufficient experimental data permitting us to know in what limit the excitation can be integrated for longer durations.

concluded that the limit of the range has not yet been attained. This range limit is reached when

$$(12) \qquad \int_{t_1}^{t_2}(E - E_0)dt = aE_0,$$

By calling I_h the photometric intensities of the luminous points measured in a horizontal section of the beam and referred to the unit distance, this may be expressed as:

$$\int_{t_1}^{t_2}[I_h f(x) - E_0]dt = aE_0.$$

or as

$$(13) \qquad f(x)\int_{t_1}^{t_2} I dt = E_0(a + t_2 - t_1) \qquad (a = 0.21 \text{ about}).$$

If the slight uncertainty which may exist about t_1 and t_2[36] be disregarded, the integral of the first member is known once for all, according to the form of the polar curve of intensities measured in the beam at unit distance and consequently x can be easily calculated as a function of the second member.

By this method we can also obtain the horizontal intensity I'_h of a fixed light giving the same limit range as the short light defined by the polar curve, for it is known that a similar fixed light is defined in function of the minimum illumination E_0 by the statement:

$$(14) \qquad I'_h f(x) = E_0,$$ [37]

whence:

$$(15) \qquad I'_h = \frac{\int_{t_1}^{t_2} I_h dt}{(a + t_2 - t_1)}.$$

The denominator of the value I'_h is a function of the flash duration $t_2 - t_1$, and, as was seen above, this duration may vary with the distance by reason of the weakening of the absolute illumination at the beginning and at the end of the flash. This shows that one cannot rigorously determine a fixed light equivalent at all distances to a flash.

[36] The more sudden the variation at the beginning and at the end of the flash, the less uncertainty is there. When it is otherwise the flashes appear considerably shorter at a long distance than at a short distance. Besides we have no pretention of giving a strictly mathematical solution.

[37] On page 14 we have shown the value of the constant E_0 which seems to be comprised between 0.5×10^{-7} and 10^{-7}.

Remarks on taking the orientation bearings of short lights.— In all that precedes, we have given our attention only to the impression produced on the retina by short lights; it may be asked, on the other hand, whether the greater or lesser shortness of the flashes has any influence on the facility of taking the bearings of the direction of the luminous point. Naturally, as in all that has been previously stated, it is only a question of comparing short flashes and lights of a duration of less than a second seen in the vicinity of their range limit.

For this purpose we have employed, for scrutinizing the luminous point a telescope moving round a vertical axis, and supplied with two vertical wires feebly illuminated to render them just visible; the values chosen for the period t and for all the observers have been 0.01, 0.03, 0.1, 0.3 and 1 second; to insure an accurate levelling of the telescope toward the luminous point, the number of flashes necessary for each observer was counted. For each observation taken the intensity of the luminous point was regulated in such manner as to give exactly the limit of the range, according to the new law established.

The following averages, each taken from the results of five observers, have thus been found.

Period of the flashes	Average of the number of flashes for levelling
$\frac{1}{100}$	4.7
$\frac{3}{100}$	4.65
$\frac{1}{10}$	4.6
$\frac{3}{10}$	4.94
1 second	5

It is therefore seen that by passing from $^1/_{100}$ of a second to 1 second, that is to say for flashes varying in time in the ratio of 100 the differences were very slight, since they do not exceed 8 per cent., differences insignificant in practice, and which, moreover, present the character of accidental errors.

It is seen that the taking of the bearings always demands about

the same number of flashes, whatever the period and that this period has no marked influence.

It is otherwise for the interval between the flashes, for experience has shown that it is not practical to increase it beyond five seconds and that the shorter the interval, the easier and the quicker the observation.

RECAPITULATION AND CONCLUSIONS.

To sum up, we have shown how, by theoretical considerations that one can ascertain the form of the most probable law for establishing the relation between the intensity and the period of a short light producing the minimum of perceptible sensation.

We next described the new method and apparatuses which allow of the experimental study of all the phenomena of perception of short lights, point sources or those of definite dimensions, by comparing two flashes of different durations, one of which serves as a standard of comparison.

By comparing a large number of measurements made by numerous experimenters, regulating to the minimum perceptible, and by reducing by the calculation of geometrical averages the divergencies which necessarily exist in measurements of this kind, we have obtained a verification, which may be looked upon as very satisfactory, of the law sought for between the illuminations and their periods of application on the pupil. In the case when uniform lights are used, we have expressed this law in the simple form:

$$(E - E_0)t = aE_0,$$

E_0 being the minimum perceptible illumination and a being a constant of time of about 0.21 of a second. Then we have shown that by simple integration one can deduce from the law of the flashes which are not uniform, their range and the intensity of the equivalent constant light from the point of view of range:

$$\frac{\int_{t_1}^{t_2} I_h dt}{a - t_2 - t_1}.$$

Finally, taking up again on this experimental basis a demonstration already expounded by one of us in 1893, we have shown,

by applying the preceding law and by taking into consideration the curves of sensation of Broca and Sulzer, that the maximum utilization of a source of light must demand short flashes without its being necessary to take any notice of an inferior limit of the period of the flashes, except in case of telegraphic signals. It, moreover, suffices that the period of the flash $t_2 - t_1$ should become a negligible quantity in presence of the constant a, in order that a maximum efficiency may be assured.

DISCUSSION.

MR. C. W. LAMY: From Buffon to Fresnel, the part of optic that pertains to lighthouse work has been a kind of not exactly terra incognita, but not much visited by scientific explorers. From the time of Fresnel to the last 80's the lighthouse lenses when not fixed were made so as to give long flashes, it being a kind of superstitious fright that a short flash will not be seen by the navigator. The apparatuses for revolving were clumsy, but happily well executed.

If I am not mistaken (I have to quote from memory) the standard heavy lenses were to make a complete revolution in 8 minutes, to consist of 8 panels so as to give a long flash every minute.

These rules were more or less strictly adhered to; some of the lenses were made of 16 panels; in some cases the number was brought up to 24, but the system of support, rollers, chariot, etc., compelled to limit the speed of revolutions to somewhat around the 8 minutes, especially for the large lenses.

At that same period, the steam navigation was making progress, especially in matter of speed, and the lighthouse scientists began to feel that creepy inner sensation that they were not keeping pace with the realized progress of the mariners and that in a short while they will probably find themselves much behind in the race for betterment.

Allard in his study for the electrification of the lights of the French coast brought forward in '83 or '84, the principle of relatively short flashes, one second to two-thirds of a second, with intervals of darkness between 3 and 4 seconds. It was the first step in the right direction.

It was given to Mr. Bourdelles, of the French Lighthouse Service, with the collaboration of the lens manufacturers, such as Sauttier, Lemonnier & Co., Barbier & Bernard, and Henry Leponte Co., to perfect the system of lightning lights which has been foreseen by Allard.

Bourdelles' ideal was a lens able to collect in one single beam of maximum power all the light that was disseminated in the 360° of the horizon of the lamps, and to repeat the beam at the minimum interval of time practicable. It was a difficult problem. It meant a complete revolution in a beautiful system running some 60 years. The machinery in use then was the antithesis of the needs,—wheels, chariots, rollers,—while beautiful parts of a beautiful machinery seemed to render the solution impossible. Everybody in the lighthouse business put his shoulder to the wheel, and the result was the discarding of the old complicated machinery and replacing it with the "Mercury float," which allowed a 2-ton lens to accomplish a complete revolution, safely and smoothly in less than four or five seconds; this solved one of the parts of the problem.

The other question, time limit for the integral perception of the flash emitted by such rapidly revolving apparatus was or had been already studied since quite a long time and Bourdelles accepted the conclusions of Charpentier that lights "lasting a longer time (than one-eighth to one-tenth of a second) were perceived integrally as if they were permanent."

The Lightning light system was established on this basis, adopting one-tenth of a second as the shortest time to obtain the integral perception of a flash.

The lens manufacturers were a little timid at first and advocated for safety sake a longer time for the emission of light, (I believe that in some cases they are correct) and the Bourdelles system of lightning lights went its way and is adopted by all the Light House world.

I must admit that the such stated limit did not satisfy me. In 1895, without knowing any of the works on the subject, except probably Allard, I had the feeling that while the principle of the one-eighth to one-tenth of a second as the limit of time may be true, there shall be between the time of perception

and the intensity of the light a sort of proportion tending toward a constant. I took the question boldly and in the preparation of the Navesink light, I took as time limit, one-twelfth of a second for the length of the flash. The results justified my ways and the light has been reported by some transatlantic steamers to be perceived, reflected by the clouds, at 70 miles at sea.

Lately, about 20 years ago, a new factor in illumination, the acetylene, came to light.

The possibilities of the new illuminant have been both over and under rated. While up to date, the amount of luminous power obtained with the naked flame is not very great, when compared to the arc light and also to the Welsbach mantles as to luminous power. The cost of gas itself has rendered it almost prohibitive, except in special circumstances, as to its use in light house lights of powerful intensity. To obviate that weak point, the acetylene engineers have tried to diminish the consumption of gas and thus the cost of running, by means of a flashing device which cuts the flow of gas during a certain period of the time. A Swedish invention, exploited since some time in Swedish lights, called the AGA (American Gas Accumulator Co.), is now used in the United States and gives good results in buoys and small lights.

The Dalen patent "Sun-valve" helped also to reduce the cost by stopping automatically the flow of gas as soon as sunlight struck the valve.

These proligomena indicate in a general manner the various steps of flashing lighthouse or orientation lights, as they are called by Blondel and Rey in their paper, from the invention of Fresnel.

First, the long and powerful flashes lasting from four to six seconds with long dark intervals;

Second, the Allard idea of short flashes with short intervals—1 second flash, 4 seconds dark interval;

Third, the Lightning Lights of Bourdelles, with a flash of one-tenth of a second and 5 seconds darkness;

And fourth, the AGA system of occulting acetylene lights with flash varying from one-tenth of a second to 1 or 2 seconds and variable intervals of darkness.

The two first are not inside of the scope of the Blondel and Rey paper. They are more or less answering to the law of Broen and Sulzer, setting at one second, the necessary time for the permanent sensation of a strong light.

As to the Bourdelles system, while affected by the laws that may be deducted from the Blondel and Rey experiments, the intensity of the beam is such that the diminished impressions on the observer's retina will not, in most cases, affect the efficiency of the light, which will remain powerful enough to be seen at the limit of its geographical range barring fogs and heavy haze.

On the contrary with the acetylene light of the AGA system, showing short flashes, the conditions are very much affected. They represent ideally the conditions of the experiments of Blondel and Rey and these gentlemen do not seem to have taken these special lights into consideration in their conclusions.

Taking as correct, the candle-power as stated by the American Gas Accumulator Co., for their lenses and lights, a dioptric lens of 30 centimeters diameter in connection with a one-half cubic foot burner, emits as fixed light, a *permanent* intensity of 200 candles.

According to Allard, a light of 200 candle-power intensity will be seen in clear weather 14.96 nautical miles. The term, clear weather, applies to a co-efficient of transparency of the atmosphere equal to 0.962 and unhappily, especially on the coast of the United States above Hatteras, this clear weather cannot be expected more than one day in twelve days or one month out of 12 months during the year.

If we select as an average of atmospheric transparency, the co-efficient that may be expected to be found half of the time, or one day out of two, the range of luminous visibility of the light falls suddenly to 9.68 miles with a co-efficient of 0.903 for atmospheric transparency. This shows that for half of the time the impression received by the observer's retina instead of being equal to 200 candle-power will be equal only to the impression made by a light of 60 candles in clear weather. This impression is the one that should be taken into consideration as it is the average situation that will be encountered by the mariner.

The light can no longer be called a strong light and falls inside

of the 2½ seconds time necessary for permanent perception as per Broca's Law, and also inside of the scope of the Blondel and Rey experiment, which can be considered as the calculation to confirm the Ribiere statement that the limit range of light of short duration increases almost indefinitely with the duration of the latter, but always remaining inferior to the permanent light as to intensity.

In the case of flashes of short duration, one-tenth and three-tenths of a second, the curve of fig. 7, showing the values of $\frac{Et}{3E_3}$, indicate clearly that the values of the initial lens intensities are to be greatly intensified to obtain at least the luminous ranges corresponding to the average atmospheric transparencies, and to keep to the acetylene flashing light their useful efficiency inside of their useful geographical ranges.

TRANSCTIONS OF THE

Illuminating Engineering Society

VOL. VII. DECEMBER, 1912. NO. 9

COUNCIL NOTES.

A regular meeting of the council was held December 13, 1912, in the general offices of the society, 29 West 39th Street, New York. Present were: V. R. Lansingh, president; George S. Barrows, L. B. Marks, C. J. Russell, James T. Maxwell, W. J. Serrill, H. E. Ives, Norman Macbeth, and Preston S. Millar, general secretary.

A resolution was passed conveying the society's best wishes for success, and assurance of co-operation as far as possible, to the recently organized illuminating engineering society in Berlin, Germany.

Authorization was given for the printing of a 10,000 edition of the illumination primer—"Light: Its Use and Misuse"—instead of an edition of 5,000 which was authorized at the November meeting. The illumination primer committee was also authorized to purchase for loan and sale as many sets of slides of the illumination primer illustrations as may be required.

Dr. H. E. Ives presented a progress report of the work which his committee—the committee on reciprocal relations with other societies—had done in the past month to promote co-operation between the society and a number of other organizations: the American Gas Institute, American Academy of Medicine, the American Medical Society, and others.

The finance committee presented a report recommending the payment of vouchers amounting to $1,061.77. Payment of these vouchers was authorized.

The finance committee was authorized to employ a public auditor to audit the 1912 accounts of the society.

Mr. L. B. Marks, chairman of the committee on factory lighting legislation, reported that his committee had held a meeting and drafted recommendations pertaining to the proposed factory

lighting bill (No. 18) of the State of New York, which were subsequently transmitted to the Factory Investigating Commission. Mr. Marks intimated that the recommendations were favorably considered by the commission and that they would be taken up at a hearing of the commission which will be held shortly.

Progress reports were also received from the 1912 convention and section development committees.

The following committee of tellers was appointed to count the ballots of the 1912 election: Messrs. Clarence L. Law, chairman; S. W. Ashe, C. O. Baker, E. N. Hyde, and G. B. Nichols.

It was decided to hold the next annual meeting of the society Friday, January 10, 1913. The following committee was appointed to make arrangements for the meeting and dinner: Messrs. C. A. Littlefield, chairman; W. A. D. Evans, E. B. Hyde, Norman D. Macdonald, and Thomas Scofield.

In accordance with a suggestion contained in a letter from Dr. F. Park Lewis, president of the American Association for the Conservation of Vision, the council authorized Dr. H. E. Ives to accept appointment as a representative of the Illuminating Engineering Society on the board of directors of the Association.

President Lansingh reported progress on the formation of a Central-west section of the society which would include the large cities of the Great Lake region.

SECTION NOTES.

CHICAGO SECTION.

At a meeting of the Chicago section, December 11, 1912, in the Western Society Auditorium, Monadnock Block, Mr. Ward Harrison, of the National Electric Lamp Association, read a paper on "Industrial Lighting."

NEW ENGLAND SECTION.

The New England section held a meeting November 18, in the Edison Auditorium, 39 Boylston Street, Boston. The subject for discussion was "Portable and Stationary Photometric Appara-

tus." A paper illustrated by various pieces of laboratory equipment was also presented by Mr. S. R. Keys of the Edison Electric Illuminating Company of Boston. A number of those present contributed to the discussion.

NEW YORK SECTION.

Mr. G. L. Hunter read a paper on Color at a joint meeting of the Art in Trades Club and the New York section in the United Engineering Societies' Building, 29 West 39th Street, December 12. About two hundred members of both organizations were in attendance.

PHILADELPHIA SECTION.

Two papers—"Calculations of Illumination Problems" by R. B. Ely and "The Use of Graphical Charts in the Design of Illumination" by R. F. Pierce—were read at a meeting of the Philadelphia section in the Franklin Institute, December 20, 1912. Ninety-two members and guests attended the meeting.

PITTSBURGH SECTION.

At a meeting of the Pittsburgh section in the auditorium of the Engineers' Society of Western Pennsylvania, November 22, 1912, Prof. H. S. Hower of the Carnegie Technical Schools discussed the subject of "The Use of Lenses in Illumination." The paper was illustrated by lantern slides and supplemented by an exhibition of a number of lenses. Fifty-six members and guests were in attendance.

A joint meeting with the Pittsburgh chapter of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Society of Western Pennsylvania, December 10, 1912. The subject of discussion for the meeting was "Street Lighting."

INDEX FOR VOL. VII.

An index for Volume VIII, which includes all the issues of the Transactions for the year 1912, will be mailed with the January, 1913, issue of the Transactions.

THE METHODS OF RESEARCH.

BY EDWARD P. HYDE.

The spirit of research now prevails. Research work is undertaken in our universities and colleges, both by faculty and by students; research departments are considered most important adjuncts to large progressive industrial organizations; research laboratories are being endowed by philanthropic citizens; and individuals everywhere, and in all branches of human knowledge are independently undertaking the investigation of problems of supposed practical importance or of personal interest. Inasmuch as effectual practise rests on the judicious application of established knowledge, whatever conduces to the enlargement or enrichment of our body of established knowledge is worthy of our highest respect and our most serious consideration. But side by side with this duty of encouragement and appreciation stands that other duty of careful discrimination between the research work that is thorough and genuine and the research work that is ill-advised and spurious.

Not long since the president and council of this society appointed a research committee to stimulate interest in the investigation of important illumination problems, to encourage sane and promising research, and to serve as a directive force in the development of the science of illumination. And it has seemed advisable to the papers committee of the society that a brief paper on "The Methods of Research" should be presented at this convention.

What is research? Knowledge comes to us at times unsought and unexpected. Discoveries are frequently fortuitous. But by research is meant the diligent, continued or laborious search after facts or principles. And the goal of research is truth. This is a most important point. Whatever may be the ulterior motive in the acquisition of truth, whether it is truth for truth's sake, as

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

in the ideal of pure science, or truth as a firm foundation for judicious practise, as in the ideal of applied science, the immediate goal in all research work worthy of the name is truth. The methods of research must, therefore, be included in the methods involved in arriving at truth, and so we turn our attention for a while to a consideration of the methods by which we arrive at truth.

Truths must be distinguished in two classes: (1) those truths which are known directly or of themselves, as our own bodily sensations and mental feelings; and (2) those truths which are known through the medium of other truths, as the theorems of mathematics. The former are the subject of Intuition of Consciousness; the latter, of Inference. It is not the place here to discuss the metaphysical question of the dividing-line between truths which are known directly and those which are known by Inference. Suffice it to say that practically all, if not quite all, of the truths of physical science are known through the medium of other truths and are hence the subject of Inference.

What then are the methods of arriving at truth through Inference? The logicians distinguish two methods, that of Induction and that of Deduction. Let us consider briefly first the Inductive Method. By Induction is meant the process of drawing a general conclusion from particular cases. Thus the Law of the Conservation of Energy and the Law of Universal Gravitation are great generalizations which cannot be *proved*, in the ordinary sense in which we speak of proving a mathematical theorem. They are expressions of our belief in the invariability of certain phenomena which have been found uniformly in a very large number of concrete cases. Many of us believe that so-called *glare* is deleterious to eye-sight. We have inferred this from observations of individual concrete cases. If true, it is an important truth in illumination arrived at by the method of Induction. The exact verity of it, and the limits within which it applies, however, have not yet been definitely established.

This last illustration suggests the two processes by which we arrive at truth by the Inductive Method. These two processes are Observation and Experiment. By Observation, as used here, is meant the passive observation of phenomena without effort to

control or modify the phenomena in any way. According to the above illustration, if we merely note that certain individuals have been exposed to strong glaring light and have subsequently had eye-troubles, and infer from this the generalization that *glare* is deleterious to eye-sight, we are making use solely of the process of Observation in our induction. If on the other hand we are not content with the results of passive observation of cases as they occur, but seek rather to control to some extent the phenomena by isolating certain factors and eliminating others, our process becomes that of Experiment. Certain phenomena are not subject to control and may only be studied by the process of Observation. Other phenomena lend themselves readily to Experiment. It should be remembered, however, that each process has certain advantages and disadvantages even in the case of phenomena to which both processes may be applied. Thus the process of Experiment is peculiarly valuable in cases where we desire to determine the various effects of a given cause, and the process of Observation has corresponding advantages in cases where we seek to find the causes of a given effect.

Unfortunately time does not permit an elaboration of the four ways in which the process of experiment may be used to arrive at truth, viz., (1) by Agreement, (2) by Difference, (3) by Residues, and (4) by Concomitant Variations. I may only commend them to you for careful study and must then pass on to a brief consideration of the second method by which we arrive at truth through Inference, viz., the Deductive Method.

We have discussed the Inductive Method first because it is the simplest and most direct method of arriving at truth by Inference. Moreover, it precedes and underlies the Deductive Method, for the starting point of the latter consists of one or more generalizations which presumably have already been established. It is true, as John Stuart Mill says, that "if we had sufficiently capacious memories, and a sufficient power of maintaining order among a huge mass of details the reasoning could go on without any general propositions: they are mere formulae for inferring particulars from particulars." But we do not have such memories or powers of maintaining order among details, and so, in our

processes of reasoning by the Deductive Method we start from generalizations arrived at by the Inductive Method.

The mode of investigation according to which we arrive at truth by the Deductive Method consists of three steps: the first, one of direct induction; the second, of ratiocination, or reasoning; and the third, of verification. The Inductive Method consists merely in inferring from the particular to the general, but in the Deductive Method, starting from previous inductions the process of ratiocination is applied, and as a result of this operation conclusions are reached which are subject to direct verification. It is a mistake to suppose that the conclusions of Deduction are distinctly new, in the sense that they were not contained in the underlying inductions involved in the reasoning, and yet the truths arrived at by the Deductive Method may be, and usually are new in the sense that they were not recognized in the inductions which formed the basis for the reasoning. As an example of this the science of geometry may be mentioned. The theorems of geometry are all deducible from the axioms or postulates which are inductions, but in which one fails to recognize *a priori* all the theorems deducible from them.

The third operation in the Deductive Method, viz., verification, is of marked importance as we shall see later on in the more specific consideration of the methods of research.

It is evident, from the hasty outline given above that these two methods of arriving at truth by inference are not independent. The basis of the Deductive Method is a previous induction. The two methods are interdependent. A young or complex science will partake more of the character of an Inductive Science, as compared with an older or simpler science. A new science has few inductions to serve as the premises of deduction, but even in a new science an effort is made to reason from the hypothetical generalizations already reached to conclusions which on being verified by observation or experiment, strengthen the inductions from which they were deduced. Thus science grows.

I regret the necessity of this somewhat academical discussion of the methods of Inference, but I see no other way of prefacing the ideas which I desire to present in regard to "The Methods of Research." As has been said, the goal of research is truth, and

hence the methods of research are none other, in their general character, than the methods of arriving at truth by Inference. Let us now apply the principles, which have been presented, to the consideration of the methods of research.

There are two general methods of research; that of induction, and that of deduction. The former is the method of Observation and Experiment, and the Inference from the concrete to the general. The latter is the method of hypothesis or theory, ratiocination and verification. Let us consider these two methods more in detail.

The Inductive Method consists of Observation and Experiment. In a new science little is known, the observations are limited, the experiments are few. There is little opportunity for ratiocination or reasoning; the greater need is for the accumulation and collection of facts in generalizations which may subsequently form the basis of ratiocination. To use the illustration referred to above, we are not prepared to reason from the induction that glare is deleterious to eye-sight because this induction itself is scarcely out of the domain of empiricism. We are investigating the matter; we are making observations and carrying out experiments. We are collating facts. We are doing research by the Inductive Method. In the development of all science, but more particularly in the development of the newer or more complex sciences, this method of research finds most valuable application.

I would further distinguish two ways of carrying out research by the Inductive Method which I shall call respectively the Definitive and the Non-Definitive methods. The distinction between these two methods is best shown by reverting once more to our illustration of the effect of *glare*. An investigator of this subject might carry out his research in either of two ways. He might, for example, lay out a definite scheme of attacking the problem. He might study experimentally first the effect of *glare* on visual acuity, then its effect on speed of reading, then its effect on fatigue, and so on. He might attempt to study by the process of Observation the intensity of the glaring light, the angle at which it is incident on the eye, the period over which the patient has been subjected to the *glare*, and the relation of these elements to the resultant eye-injury. In either of these two cases,

both of which are examples of research by the Inductive Method,—one by the process of Experiment and one by the process of Observation—the investigation has proceeded according to a definite plan, has followed a definite scheme. Such research by the Inductive Method I would call Definitive.

On the other hand many investigations are carried out by the Non-Definitive method, and many investigators have a tendency to work in this way. Thus, in the illustration of the study of *glare*, an investigator might set out to study the problem without any definite scheme of attack, or any preconceived notions of the causal relations between the resultant effects and the possible causes. He would, in a more or less random fashion, vary the conditions and note the result, and attempt ultimately to discover the important element in the problem. The method is haphazard, fortuitous, Non-Definitive. And yet at times it is most valuable. Moveover, it should be emphasized that in research by the Inductive Method the process is seldom entirely Definitive or entirely Non-Definitive. The investigator with the scheme is ever alert or should be ever alert to recognize some unsuspected phenomenon which flashes out into prominence as important. And the schemeless investigator will always, or should always *follow-up* any phenomenon which attracts unusual attention.

The two processes are interwoven, and very few, if any, researches are made exclusively by one or the other. And yet it is very easy to point to investigators who tend to work according to one or the other of the two processes. I am at a loss what to say regarding the relative merits of the two methods. The Non-Definitive Method is at times, and in the hands of certain investigators, of the greatest value, but I see no way of laying down rules for procedure according to this method. Since it is more or less haphazard there can be no rules. We must rely entirely on the personal equation of the individual. The Definitive Method, on the other hand, is conformable to a formula of procedure. Inasmuch as the general scheme of procedure by the Definitive Inductive Method has much in common with that of the Deductive Method, I shall give the formula for the two at the same time.

We turn now to a consideration of the Deductive Method of research. This is the method of hypothesis or theory, ratiocination and verification. We have seen that this method of arriving at truth consists in argument from previous inductions or generalizations to conclusions which are subjected to verification by Observation or Experiment. This is peculiarly the method of the mathematical sciences. The verification confirms the conclusion and strengthens our belief in the generalizations which served as premises. These generalizations may be generalized facts as in the classical illustration—All Men are Mortal; or they may be generalized principles such as the *theory of gravitation* or the nebular *hypothesis*. A general principle which possibly or even probably underlies or explains certain phenomena is frequently termed a *hypothesis*. Arguing or reasoning from this hypothesis certain conclusions are derived. These conclusions are put to test by Observation or Experiment. If the conclusions are not confirmed the hypothesis is shown to be false and not to be a true induction or generalization. If the conclusions are found to be true, the hypothesis is strengthened. If the deductions from the hypothesis are found consistently to be true the hypothesis becomes a *theory*, and is classed with the other great principles of the science.

Just as it is impossible to lay down rules for carrying out a research by the Non-Definitive Inductive Method, so is it impossible to lay down rules for deciding upon the scheme of a research according to the Definitive Inductive Method, or of determining upon a specific deduction according to the Deductive Method. These things are matters of individual creative imagination and not subject to formula. Granted, however, a definite scheme of research (Definitive Inductive Method) or a deduced conclusion (Deductive Method) it is quite possible to lay down a general formula which will be helpful in carrying out the experimental work. Such a general plan of procedure is outlined below:

1. Exact definition and statement of problem.
2. Study of literature pertinent to the problem.
3. Determination of experimental method.
4. Choice or design of apparatus.

5. Isolation of specific phenomenon to be studied, or of quantity to be measured, and elimination of complicating phenomena or quantities.
6. Preliminary investigation of instruments used.
7. Investigation and discussion of sources of error.
8. Careful analysis of results.
9. Justifiable conclusions.

In an early paragraph of this paper emphasis was laid on the fact that the goal of research is truth. Whatever may be the stimulus for the attempt to ascertain the truth, whether it be truth for truth's sake, or truth as the basis of sound practise, the immediate object in every true research is truth. It seems expedient in concluding the paper to return to this subject to reiterate the importance of the right attitude toward research, and to sound a word of caution against those two classes of investigators whose well-meant efforts serve rather to retard than to assist the development of science. The charlatan, the imposter needs no consideration, but there are genuine men whose contributions in the name of scientific research are more fundamentally and permanently harmful than the wild claims of the charlatan. I refer to the narrow, incompetent investigator and to the broad speculator. The former can see but one side of a problem, and his incompetency is further reflected in his restricted ability to impose the proper limitations on his conclusions. The latter is continually inferring generalizations from inadequate data, or deducing conclusions from non-established inductions. There is a place for hypothesis, and there is need of speculative imagination, but he who confuses speculative hypothesis with established principles and leads others into such error is inhibiting the development of science. And it is very difficult to counteract the effect of such unjustifiable speculation, for it is usually in the domain of limited knowledge, and his is a thankless task who urges the inadequacy of fact to justify the speculation, but who is unable himself positively to controvert the speculation. Let us all endeavor to be more severe critics of our own work, and more discriminating critics of the work of others.

DISCUSSION.

Dr. C. H. Sharp: Illuminating engineering deals with a science which is only now becoming systematized. A great many of the facts that could be ascertained are not yet known, and there are in some lines very insecure bases for generalizations. A great deal more needs to be done in the way of accumulating facts. In many lines, for instance in the study of glare, the science is in an undeveloped state. I think we can be perfectly frank and say that in this society we have probably suffered by some kinds of research such as Dr. Hyde has mentioned; that is, research by men who are enthusiastic but inexperienced and given to generalizations which are broader than the facts warrant. We must remember that researches in illuminating engineering are likely to be in the psycho-physiological domain. In this domain the results obtained must be very carefully gone over and scrutinized and must rest on the basis of a great mass of experiments. Personal errors and idiosyncrasies are likely to be of very great relative magnitude and to have a great influence on the ultimate results. It is very important to obtain a very great mass of data before reaching a definite conclusion. I think we have had a number of papers before our society in which the conclusions were reached in the physiological and psychological field from bases which were inadequate to justify them. So, in sounding a note of warning and in pointing out how harmful may be conclusions which, though not well founded, cannot without great labor be controverted, Dr. Hyde has done a very great service and I think the future work of the society ought to benefit by his paper.

Dr. H. E. Ives: I want to sesond, if I may put it that way, the remarks of Dr. Sharp. I think there is no paper more timely than this one on "The Methods of Research." It has been my luck lately to have had conversations with men who have done research work in this society. I have about come to believe that the most valuable function of one trained in research methods is advisory. I once heard Professor Lippmann say, "I have no chance now to do any research; it takes all my time to direct people and see that they are not using incorrect methods of research." In discussions I have had on the subject of methods

of research certain errors or tendencies have stood out very prominently; consequently I have found it possible to make a list of the most prominent errors; perhaps, by way of making more specific the comprehensive treatment given by Dr. Hyde I may be permitted to give them here:

First, Insufficient analysis of the problem. We frequently find for instance variations in illumination being studied where the phenomenon on analysis is really one of intrinsic brilliancy. At another time everything is ascribed to specular reflection, when a brief analysis if made, shows no specular reflection present.

Second, Insufficient study of the method of measurement. Investigators are prone to take a method and apply it without question as to whether it is the proper method to apply or not. They try to measure temperature with a foot rule.

Third, The error of overlooking the assumptions upon which the work has been based. Each report of a research should be in parallel columns: on one side the assumptions and on the other the conclusions. Then when one reaches the end and sees the conclusions drawn, he can look across and see the hypotheses.

Fourth, A clear distinction is not made between the experimental results and the author's conclusions. Often they are very different things. Sometimes the investigator's experiments are properly made, but his conclusions are wrong. Experimental results very often can be placed upon another foundation and made to reveal truth. It seems to me that one of the best things the Society could do would be to prepare a manual of how to write up an investigation.

Dr. Hyde says, "There is a place for hypothesis and there is need of speculative imagination, but he who confuses speculative hypothesis with established principles and leads others into error is inhibiting the development of science. It is very difficult to counteract the effect of such unjustifiable speculation, for it is usually in the domain of limited knowledge, and his is a thankless task who urges the inadequacy of fact to justify the speculation, but who is unable to controvert the speculation." That is true, but suppose we leave the Illuminating Engineering

Society and go into another field. Research is very much like the work of the detective. Suppose our Sherlock Holmes has brought forth a suspect. Suppose he says, "We have not been able to *prove* anything against this man, but we think he did it and if you can't produce the real criminal this man will have to do; we have got to have a hanging anyway!" We don't tolerate such reasoning in criminal procedure; I don't see why we should in research.

DETERIORATION OF GAS-LIGHTING UNITS IN SERVICE.*

BY R. F. PIERCE.

Deterioration, as applied in this instance, properly embraces only the results of such changes as are functions of time, and inherent in the apparatus used, the illuminant supplied, and the conditions of use under the best modern practise.

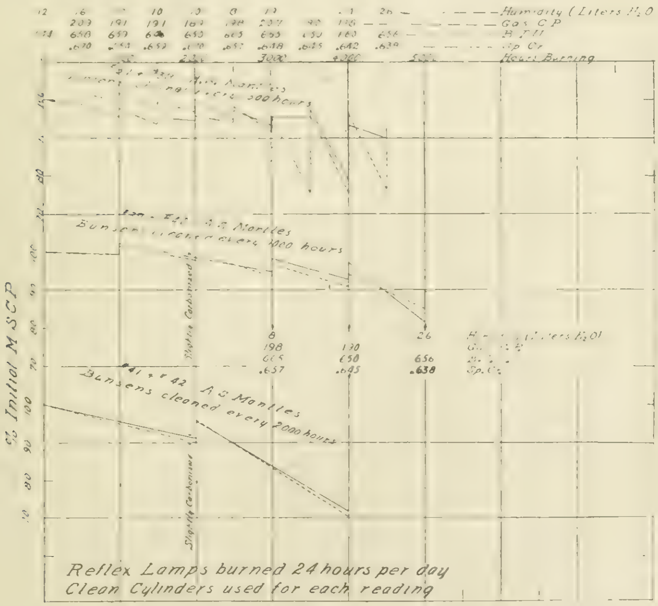


Fig. 1.

Mantle deterioration is analogous to the deterioration in luminosity and efficiency of the filament of the electric incandescent lamp. The deterioration in illumination due to deposit of dust upon the glassware corresponds to the effects of the same cause upon glassware used with other illuminants, while such deteriora-

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

tion in candle-power and efficiency as may be due to fouling of the burner has no analogue among other illuminants. The effects of varying gas conditions correspond to those of voltage fluctuations but are of less importance, and come under the head of service factors rather than deterioration factors.

There are no other variables of sufficient importance to require allowance or consideration in the design of gas-lighting systems.

The test hereinafter reported was designed to separate the above factors with reference to the performance of gas lamps

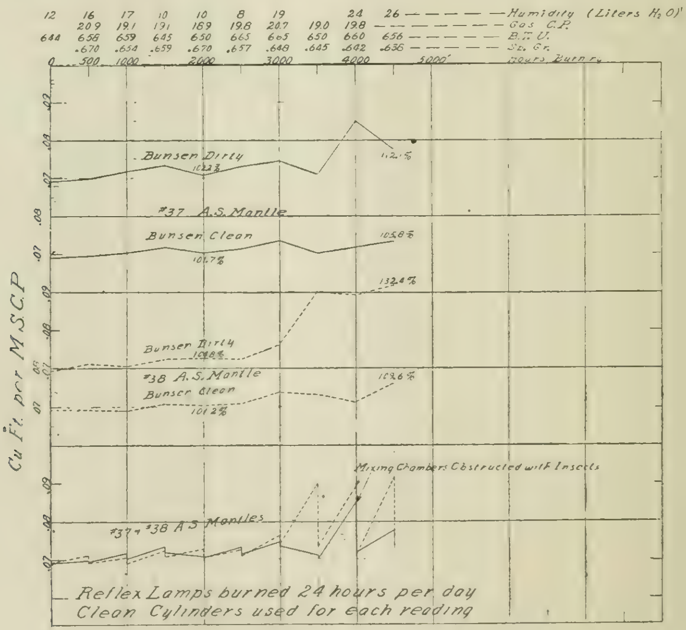


Fig. 2.

under different conditions of actual service. While it is rather difficult to completely separate the different influences with reference to their effects, this separation may be carried to such a point as to satisfy every practical requirement, and this test was conducted primarily for the purpose of obtaining engineering rather than scientific data.

Twelve inverted burners, selected at random from factory stock, were equipped with artificial fiber mantles similarly se-

lected, and were adjusted for maximum incandescence by the eye alone, operating upon mixed gas (80 per cent. water and 20 per cent. coal) at 2.5-in. (6.35 cm.) pressure.

The test was conducted in a room in which the air was heavily charged with inorganic dust, to such an extent that a visible deposit settled over night upon newly cleaned surfaces.

Of the 12 units, six were burned 24 hours daily, and six 5 hours daily. Of each six, 3 had their cylinders cleaned at regular intervals and 3 were left untouched.

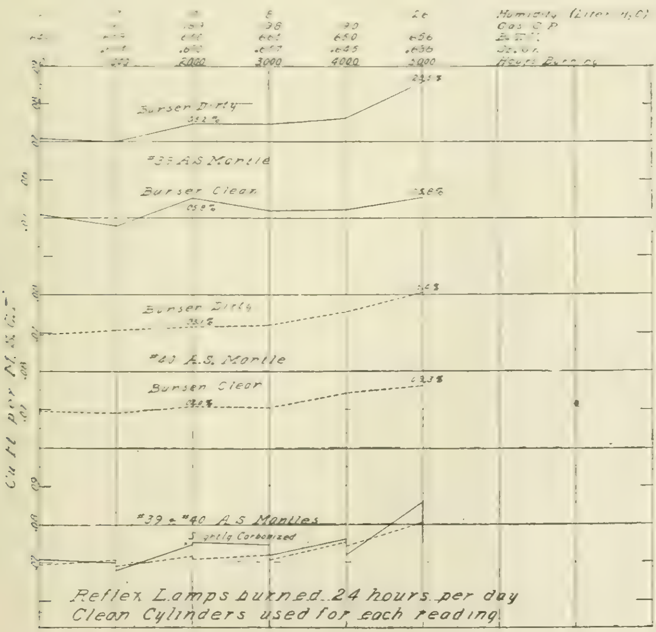


Fig. 3.

The cylinders of the continuous burning units were cleaned every 14 days and those of the intermittently burned units every 10 days.

In addition to these units, 6 others similarly selected, were burned continuously, 2 having their bunsens cleaned every 500 hours; 2 every 1,000 hours; and 2 every 2,000 hours.

In all cases candle-power and gas consumption readings were taken before and after each cleaning, the lamps being removed

from the test bar to an Ulbricht sphere located on the floor below, and replaced after reading.

Figure 1 shows the candle-power life curves obtained from the test of the second group of 6 units. The excessive burner deteriorations indicated at 3,500, 4,000, 4,500 and 5,000 hours were due to the omission of screens from the air ports and the advent of large numbers of insects which became deposited in the distributors of the lamps. Eliminating these abnormal results an

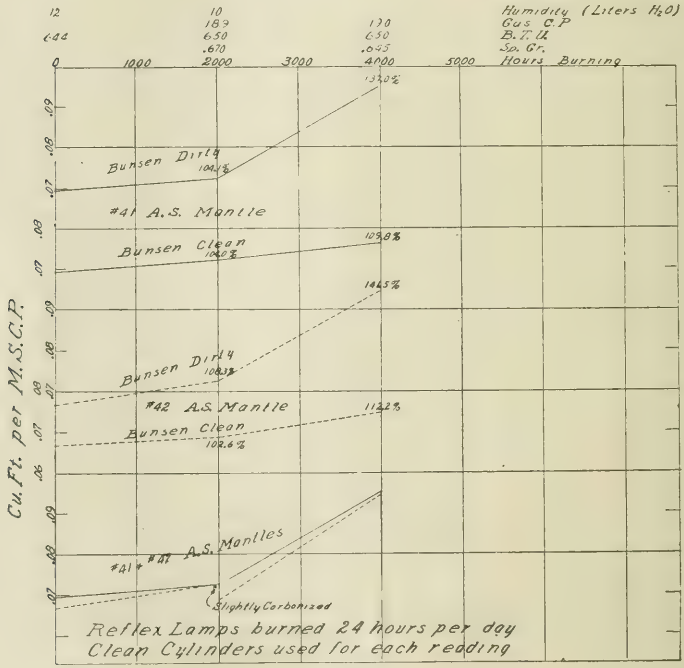


Fig. 4

average deterioration of 2.14 per cent. per 500-hour period is shown for units 37 and 38. Units 39 and 40 show an average deterioration of 2.6 per cent. per 1,000 hour period and 40 and 41 show 5.35 per cent per 2,000-hour period. Evidently, the greater portion of dust deposit in the burner takes place during the first 500 hours.

Figures 2, 3 and 4 show specific consumption curves for the same units. The curves marked "Bunsen clean" show the de-

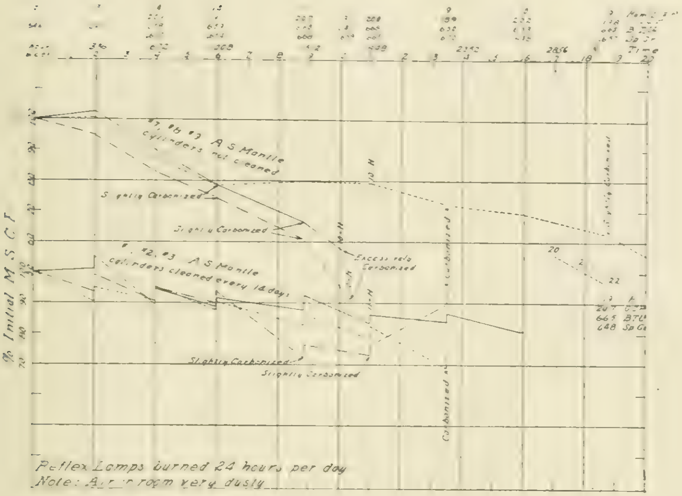

Time
% Initial M S C P
A S Mantle
cylinders not cleaned
Slightly Carbonized
A S Mantle
cylinders cleaned every 14 days
Carbonized
665 BTU
648 Sp Gr
Reflex Lamps burned 24 hours per day
Note: Air in room very dusty

Fig. 5.

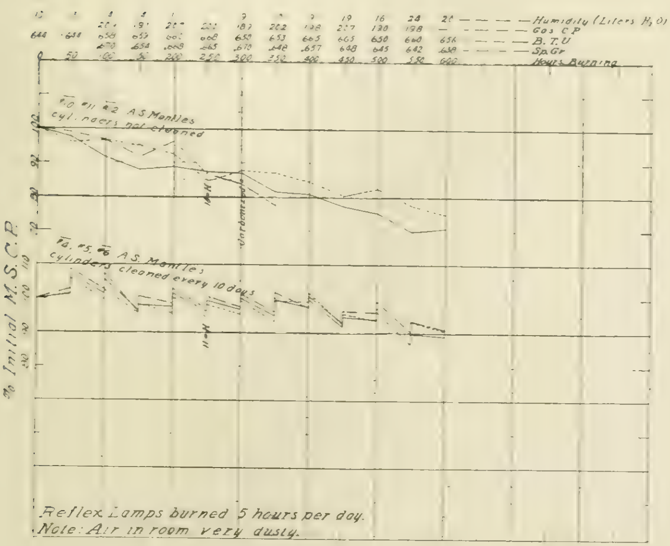

Humidity (Liters H_2O)
Gas C P
B.T.U
Sp.Gr
Hours Burning
A S Mantles
cylinders not cleaned
Carbonized
% Initial M.S.C.P.
A.S. Mantles
cylinders cleaned every 10 days
Reflex Lamps burned 5 hours per day.
Note: Air in room very dusty.

Fig. 6.

preciation in mantle efficiency alone. It will be observed that the great variations in atmospheric humidity occurring did not affect the performance of the units to any noteworthy extent. At the end of the test the increases in specific consumption were 5.8, 10, 5.6, 8.5, 10, and 11.2 per cent., an average of 8.5 per ecnt.for a period of from 4,000 to 5,000 hours.

The effects of deterioration in glassware are shown in figures 5 and 6 from which maximum, average, and minimum increases due to cleaning are found to be 6.4, 4.3, and 2.8 per cent. re-

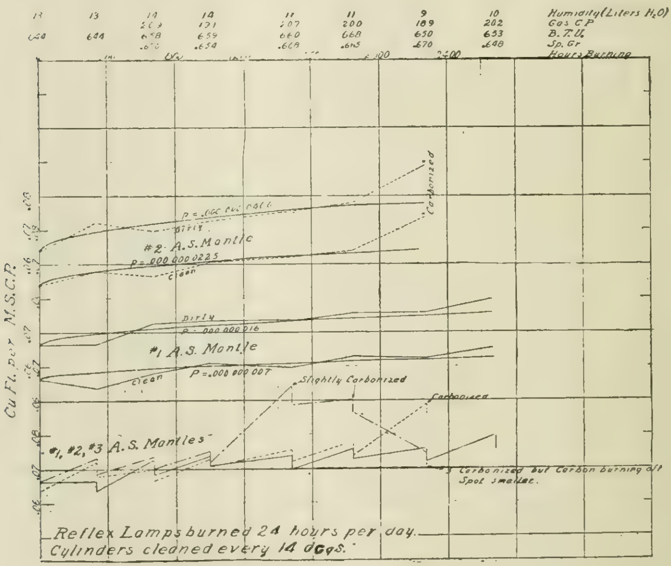


Fig. 7.

spectively, for the units burned 24 hours daily and cleaned every 14 days, and 6.3, 3.8 and 1.8 per cent. for those burned 5 hours daily and cleaned every 10 days.

Evidently, the deposition of dust is a function of time and exposed surface, and is not greatly influenced by the burning of the lamp. This is further shown by a separate test conducted over a period of 21 days on gas and electric incandescent lamps. The results follow:—

Inverted gas lamp, clean cylinder, burning 4.2 per cent. loss.
Inverted gas lamp, clean cylinder, unlighted 3.5 per cent. loss.
Average of four.
60-watt tungsten unlighted 3.8 per cent. loss.
25-watt tungsten unlighted 4.5 per cent. loss.
Average of two.

Figures 5 and 6 show the relative effects of continuous and intermittent burning with reference to mantle deterioration.

Figure 6 shows that the intermittently burned units with cleaned cylinders depreciated 7.16 per cent. in candle-power in 600 hours; whereas, from figure 5 it appears that the average deterioration of continuosly burned units in 672 hours was 5 per cent..

The difference between the effects of continuous and intermittment burning appears to be negligible with this type of mantle.

A comparison of groups 1, 2 and 3 (fig. 5) with groups 7, 8 and 9, shows that at the end of 1,000 hours the average depreciation of units with uncleaned cylinders was 23 per cent. while those with cleaned cylinders depreciated by 8 per cent.

The average increase per cleaning of the latter as shown by the original data was 4.6 per cent. or 13.8 per cent. for three cleanings, making 21.8 per cent. for the corresponding deterioration had the three deposits of dust been superimposed and allowed to remain. This would indicate that up to 1,000 hours the deposition of dust is a straight line function of time. At 2,700 hours, however, the uncleaned unit No. 8 had deteriorated 31 per cent., while No. 7 had deteriorated but 14.5 per cent. Adding the aggregate increases due to cleaning to the latter gives 43.6 per cent. indicating that between 1,000 and 2,700 hours the rate of dust deposition decreases, probably due to the adhesion between glass and dust being greater than the cohesion between dust particles. After the lamps had been operated for some time, it was found that dust particles tended to collect in the bottom of the globe rather than to adhere to the side.

From the results of this test it was desired to evaluate the useful life of the mantle under operating conditions, and for this purpose, specific consumption curves were plotted; these are shown in figs. 7, 8 and 9.

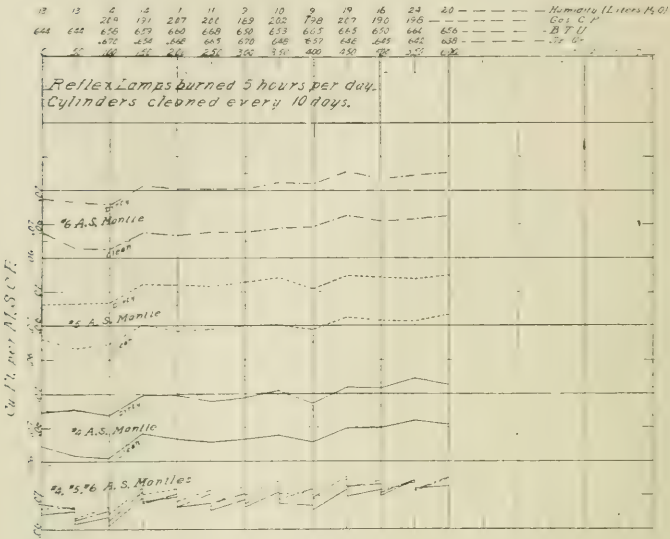

Reflex Lamps burned 5 hours per day.
Cylinders cleaned every 10 days.
#6 A.S. Mantle
#5 A.S. Mantle
#4 A.S. Mantle
#4. #5. #6 A.S. Mantles
Cu. Ft. per M.S.C.P.
Humidity (Liters H2O)
Gas C.P.
B.T.U.
Sp. Gr.

Fig. 8.

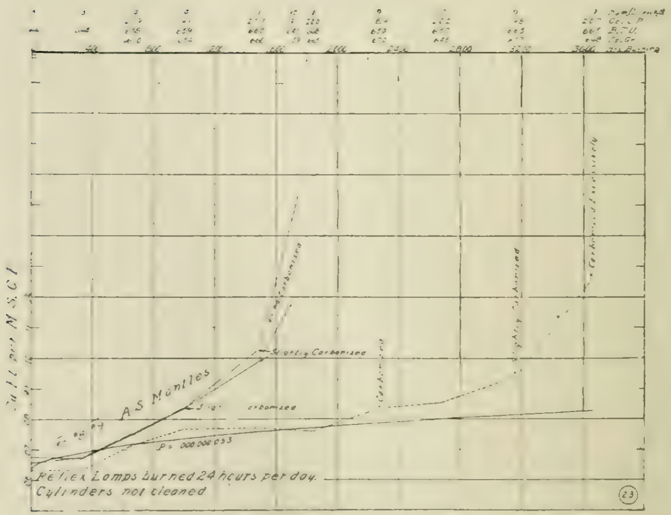

A S Mantles
Slightly Carbonized
Reflex Lamps burned 24 hours per day.
Cylinders not cleaned
23

Fig. 9.

These curves include the effect of burner deterioration as it is not usual practise to clean burners except when replacing mantles. The approximately parabolic form of the curve is probably due to the fact that burner deterioration is not a straight line function of time.

Inspection of the curves shows that a parabola having the formula,

$y = \sqrt{2px}$ sufficiently approximates the form of the curve where y = increase in specific consumption above the initial

x = elapsed time,

p = constant,

Let W = initial specific consumption.

T = total operating cost per c-p. hour at end of X hours,

A = cost of mantle per initial c-p.,

B = cost of gas per cu. ft.

$$\text{Then } T = A + \int_0^X B\sqrt{2px}\,dx + BWx$$

$$= A + \frac{2}{3}B\sqrt{2p}\,x^{\frac{3}{2}} + BWx.$$

The cost per c-p. hour is then

$$\frac{T}{x} = \frac{A}{x} + \frac{2}{3}B\sqrt{2p}\,x^{\frac{1}{2}} + BW,$$

which is a minimum when

$$D_x\left(\frac{T}{x}\right) = 0 = -\frac{A}{x^2} + \frac{\sqrt{2p}\,B}{3\sqrt{x}}, \text{ or when}$$

$$X = \sqrt[3]{\frac{9A^2}{2pB^2}}.$$

Assuming \$1.00 gas and a mantle cost of 30 cents, the useful life of the mantles 1 and 2 is 2,650 and 1,750 hours respectively, and that of No. 8 (with uncleaned cylinder) 1,325.

It is only fair to state that the mantles with which this test was conducted were an early product of lower efficiency than is now being obtained with the same rate of deterioration in candle-power and efficiency.

The present product has under the same circumstances about twice the useful life.

The question of mantle mortality has been purposely avoided as none of the mantles failed from mechanical causes.

The minimum, maximum and mean initial candle-powers and efficiencies were 54.8, 58.2, 27.8, and 14.10, 15.84 and 14.96, respectively, the average variation from mean candle-power being 4.66 per cent. and from mean efficiency being 5.15 per cent., indicating that no allowance need be made for non-uniformity in initial mantle and burner performance.

The separate deterioration rates from different sources at the end of 1,000 hours continuous burning average as follows:—

	Per cent.
Mantle alone	2.5
Burner alone	2.5
Glassware alone	10.0
Total	15.0

These deteriorations were obtained under quite unfavorable conditions, especially as regards the dusty condition of the air, and there is no reason to believe that under ordinary conditions of gas supply, there should be any difficulty in duplicating these results in average practise.

As far as the design of illumination is concerned, it is evident that there is no substantial difference between the performance of gas and electric units, and the quantities of illumination required and initially obtained by the one will be equally suitable for the other.

DISCUSSION.

MR. WARD HARRISON: On the second page of the paper I notice a statement that the effect of varying gas conditions corresponds to that of voltage fluctuation, but is of lesser importance. An investigation of 61 plants by the Wisconsin Rate Commission has shown that for the average central station in that state, the extreme variation between maximum and minimum pressure, measured at the consumers' premises during the period between the hours of 5 and 12 p. m., is 6.15 per cent. In other words, the extreme fluctuation is only something like 3 volts on either side of the mean; ordinary fluctuations are very much less. These figures apply to comparatively small plants; in the large cities I believe the regulation would be found to be better than 2 per cent. The variation which 1 per cent. change in voltage

causes in the candle-power of a tungsten-filament lamp is well known and it would seem that before drawing a general conclusion as to the relative seriousness of fluctuations in gas and electric pressures, we should have data as to the change in candle-power of a gas lamp with changes in pressure and also some information as to the ordinary fluctuation in gas pressure for representative cities of this country. It seems to me that the better and safer course for the Society to pursue would be to consider the characteristics and performance of an illuminant simply on its own merits, without drawing direct comparisons with any other types, for the latter course leads only too frequently to prolonged petty discussions which benefit no one.

On the seventh page reference is made to tests on lamps burned continuously and to others on lamps burned 5 hours per day. I should say that the latter tests are of more practical value, since they more nearly represent working conditions. The statement regarding the negligible difference between intermittent and continuous burning would seem to require further proof because of the shortness of the period over which the intermittently burned units were tested, and also because of the relative magnitude of the unavoidable photometric error in comparison with a total difference between initial and final candle-power values of something like 5 per cent.

On the basis of the average candle-power values given on the tenth page and an average efficiency of 14.96 candle-power per cu. ft., the consumption for these inverted mantles was approximately 3.7 cu. ft. per hour. This is a considerably higher figure than previously given for lamps operating on gas having a 655 B. t. u. content. Tests on lamps supplied with 600 B. t. u. gas would probably show a consumption of more than 4 cu. ft. per hour.

I should like to ask just what sort of maintenance was given the burners of the lamps on test. It has been found that cleaning the burners is rather an indefinite process. One man may clean the lamp in the usual manner and secure a given candle-power and then if the same unit is given to a second man, he will perhaps go through the ports and passages with extreme care and will get a 25 or 30 per cent. higher value. Of course, the main-

tenance depends entirely upon the man on the job. It is difficult to duplicate laboratory practise under the conditions existing in the average store or shop.

In regard to the actual laboratory candle-power deterioration factors which are reported in this paper, I would say that they check very closely with the results which the National Electric Lamp Association has obtained from similar tests. The Association had no opportunity to test artificial silk mantles as yet, but the tests on Ramie mantles showed only slightly greater deterioration than those recorded here, a difference which could readily be accounted for by the improvement in the quality of the mantles. The factors given for deterioration due to dust seem very close to those which have been found in electric installations. On the other hand, the Association has gone quite thoroughly into the testing of gas lamps in service and for some reason the results of such tests have not checked with the results of Mr. Pierce's or those of the Association's own laboratory tests. Just why this should be so, is difficult to explain; probably the care exercised by the man in charge of the lamps has a great deal to do with it. A very thorough investigation was conducted in Detroit on a trial installation of gas "arcs" of a recognized standard make. After about five months they were found to have deteriorated something like 53 per cent. under what is considered the best maintenance of any city in the country. Electric lamps installed under similar conditions showed a deterioration of 17.8 per cent. for the same period of about 1,400 burning hours. Some question was raised in regard to these tests and for that reason they were repeated. In both cases they were found to be in close agreement with those just quoted. Full data on these tests were given in the *Electrical World*, April 6, 1912.

In the *Proceedings* of the American Gas Institute for 1910, Mr. Schofield reported a series of service tests, which he conducted in the offices of the Consolidated Gas Company of New York City. These tests showed about 30 per cent. lower intensity than those obtained when the lamps were first installed. It is by no means easy to account for such discrepancies, but they appear in all tests published up to this time; reports of further investigations of the subject would form a valuable contribution

to the TRANSACTIONS. Under the existing circumstances it would seem that the closing statement in Mr. Pierce's paper is a rather sweeping one. It reads: "As far as the design of illumination is concerned, it is evident that there is no substantial difference between the performance of gas or electric units, and the quantities of illumination required and initially obtained by the one, will equally be suitable for the other."

I have just one other question and that is in regard to the gas used for these tests. From the description—mixed gas, 80 per cent. water and 20 per cent. coal containing, 655 B. t. u.—I infer that it was a special gas manufactured for the purpose. I should like to know whether this was the case or whether it was taken from the city mains.

MR. R. F. PIERCE (In reply): Regarding Mr. Harrison's remarks on the influence of gas pressure; I referred to the influence of a certain percentage of variation. A 5 per cent. fluctuation in gas pressure will not have the same effect upon the performance of gas lamp as a 5 per cent. fluctuation in voltage upon an electric lamp. Of course, the variation which may be found in any one plant or any number of plants does not come into the discussion at all. That is a service matter and applies solely to the company furnishing the illuminant.

Regarding the discrepancy between nominal and rated consumption: mantles are constantly being improved and this may result in making the mantles larger or smaller and consequently consuming more or less gas; but the efficiency varies but slightly. At the time that the rated consumption of 3.3 cubic feet was determined upon, that was the average consumption of a large number of lamps and mantles. With mantles as furnished today, it would be somewhat more than that, but the efficiency would be substantially the same. At any rate, the question of consumption is outside the scope of this paper. Furthermore, the mantles tested were an experimental product of comparatively low efficiency, as stated in the paper.

As regards the sort of maintenance given the burner, that was made very simple for the express purpose of eliminating the personal factor as far as possible. The burner was simply unscrew-

ed and blown through. It seems as though one man would perform such a simple operation as well as another.

As regards the comparison between the deterioration of mantles burned five hours per day and those burned continuously, the deterioration curves seem to be quite definite; the deterioration of the continuously burned units was 5 per cent. at 600 hours and that on the intermittently burned units 7 per cent. What future developments will bring forth is problematical, but I do not anticipate any very great difference. The discrepancy which does take place is due to dust. Inorganic dust has a fusing effect which breaks down the cell walls of the mantles; but, inasmuch as the new mantle has no cells, this is expected to have little effect.

Mr. Harrison has referred to some service tests which have indicated considerably greater deteriorations than appear in this test. Some of those tests have received considerable publicity and it is unfortunate that no evidence has been submitted to show that the discrepancies are due to inherent deterioration rather than to quality of gas service or the use of poor mantles.

The latter considerations refer purely to the willingness of the gas company and customer to furnish the best available conditions and equipment, and are not chargable to the incandescent gas lamp. Certainly Mr. Harrison would not accept as typical of electric lamp performance a test of an installation in which voltage fluctuated over 8 or 10 per cent. and very inferior lamps were used—some in a condition practically approaching outage. Yet a similar condition in a gas lighting installation is often cited as typical, without any qualifying reference to the external factors which may have existed to account for the results.

It should also be noted that the gas lamps in the Detroit test were so-called "arc lamps" containing gauzes which foul quite rapidly and are (in the particular design referred to) apt to be so difficult of removal for cleaning as to seriously reduce the chances of their receiving proper attention. This installation, cannot therefore be compared with those upon which the test reported in this paper was conducted.

As to the tests in the offices of the Consolidated Gas Company at New York, the data submitted was too inadequate to locate

the source of the discrepancy. The sort of mantles used was not stated, but as only cotton mantles were available at that time, some grade of cotton mantle must have been used. All cotton mantles deteriorate rapidly in candle-power.

None of the tests reported showing considerable deteriorations in gas lamps has been accompanied by sufficient data to justify any conclusions whatever. The grade of mantle used is seldom reported; the quality of gas never. Both of these are very important factors. At any rate, no evidence has been adduced to show that the inherent deterioration of a gas lamp in practise is greater than in the laboratory. It is obvious that conditions of service are frequently different, but this is entirely outside the scope of this paper.

If in future tests Mr. Harrison will take pains to see that gas pressures and quantities, as expressed by candle-power, specific gravity and calorific value are identical (within reasonable limits) and the mantles are of the best commercial quality, he will find that the large discrepancies found in many instances will be greatly reduced.

As to Mr. Harrison's inquiry regarding the quality of gas furnished for the test, I would say that ordinary city gas was supplied from the storage holders of the Philadelphia Gas Works.

Regarding the last statement which Mr. Harrison criticised, it was not intended to be taken quite so broadly. One may assume that if mantles of the best grade are used, and if the maintenance is substantially equivalent to that noted in this test, there is no reason why the rate of deterioration should be any different.

I have tested several installations where the service deterioration was not more than 18 or 20 per cent. over a one thousand hour period; on the other hand, there are several in which it rises to 45 or 50. This includes deterioration of mantles, glassware and burners.

The comparison between gas and electric lighting units to which Mr. Harrison refers as undesirable was inserted simply to call attention to the fact that initial illumination intensities which have been found desirable for various classes of service with

electric lighting units may also be utilized in the design of gas lighting systems.

Most of the information upon this subject has been contributed by investigators of electric lighting installations.

It is surely desirable that the engineer be able to make comparisons between different systems of illumination without the necessity of applying factors of varying size in the calculations for different illuminants.

The test reported in my paper was in no sense a laboratory test in the accepted sense of the term; it was a service test conducted in a building which happened to be used as a laboratory and to contain laboratory facilities. None of these facilities was, however, used to improve the performance of the lamps under test. There was only one particular in which these lamps operated under more favorable conditions than could have been obtained in any commercial service where pains were taken to insure good gas and maintenance service, and that was in regard to the uniform quality of gas furnished for testing, which of course was absolutely necessary in order to secure comparative results on mantle, burner and glassware deterioration.

It is perfectly evident that the existence of a substantially greater deterioration in actual service must be due to factors entirely outside the scope of this paper—improper care of burners, mantles of poor quality, or exceptionally dirty gas.

It is true that even with uniform pressure, clean gas, good maintenance and high grade mantles, there might be a greater discrepancy between initial and final light output than is indicated in my results, due entirely to the furnishing of different qualities of gas at the two periods under comparison. This obviously has nothing to do with the deterioration of the gas-lighting unit itself. It is entirely analogous to the furnishing of electric current at different voltages at different times. If an electric lighting installation be operated at 110 volts initially, and at the end of 1,000 hours the voltage be reduced to 100, it is perfectly obvious that the falling off in illumination has nothing whatever to do with the deterioration of the electric lamp. The limits of this paper as set forth in the opening paragraph eliminate all questions of this nature.

Mr. J. P. Conroy (communicated:) It has been stated that various gas installations have shown a very large candle-power deterioration from the initial candle-power even though maintained by the gas interests. Below is given a series of test data supplied by the Electrical Testing Laboratories. In parallel columns are given the horizontal foot-candle intensities measured in March of 1912, and again on October 31 of the same year in the millinery store of Galligan & Company, 663 Broadway, New York.

Location No.	First test Foot-candles	Second test Foot-candles
1	2.58	2.60
2	2.58	3.00
3	2.58	2.73
4	4.56	3.22
5	4.23	3.47
6	4.39	4.50
7	4.23	3.12
8	7.15	4.90
9	4.23	3.77
*10	6.51	5.90
11	5.37	4.57
12	4.23	3.40
*13	8.62	6.33
14	7.48	5.47
15	1.62	1.40
16	1.79	1.62
17	1.62	1.63
18	1.87	1.69
19	2.03	1.72
20	1.50	1.37
21	1.58	1.35
22	1.79	1.60
23	2.03	1.64
24	1.79	1.42
Average	3.24	2.14

* Not included in average.

It will be further seen from location of the test stations (see Fig. A) on the accompanying cut that the average of all the readings is a fair average illumination of the installation. The deterioration over the six months elapsing was but 15.4 per cent. The installation has been maintained by the regular General Gas

Light Company's maintenance service and the trim day previous to the test was October 25. Orders were given to the Electrical

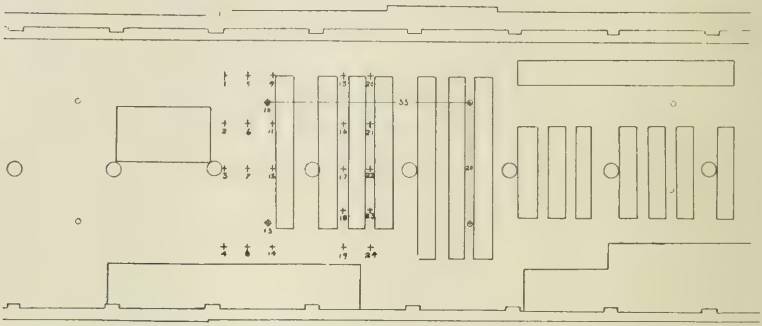


Fig. A.—Location of test stations at which illumination readings were taken in the store of Galligan & Co.

Testing Laboratories to make the test on this day and they were at liberty to do the testing at their own convenience and without the knowledge of the General Gas Light Company.

THEORY AND CALCULATION OF ILLUMINATION CURVES.*

BY FRANK A. BENFORD, JR.

This paper is divided into two sections. The first section gives the derivation and classification of illumination curve formulae; the second section gives a graphic method of using some of these formulae. Only those cases that come within the following conditions are considered.

1. The law of inverse squares is a sufficiently close approximation, that is, the source of light is a "point" source.

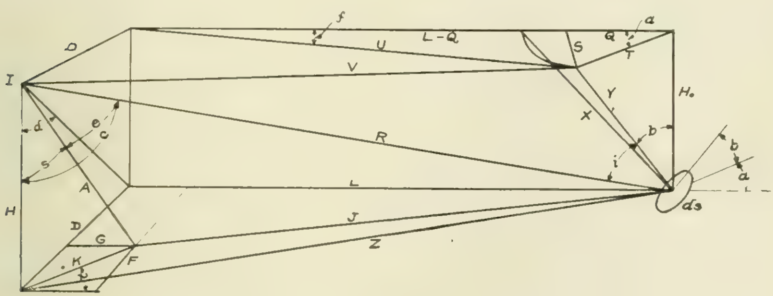


Fig. 1.

2. The illumination varies as the cosine of the angle of incidence. This condition is a corollary to the first condition, and is of the same degree of accuracy.

3. The distribution of light is symmetrical about an axis through the source.

4. The line of illumination is a straight line.

SECTION I.

In fig. 1 the source is at I, with its axis of symmetry along A, making an angle *s* with H, a perpendicular to the reference plane which contains the line of illumination L. The angle through which the source is rotated about H is denoted by *t*, and is meas-

* A paper read at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

ured from an axis parallel to L. The elemental surface ds which is illuminated by the ray along R, moves along L, and its angular position is given by the dihedral angle b and the angle a in the reference plane. Y is perpendicular to the surface ds, and the angle i between Y and R is the angle of incidence.

It will be found convenient in deriving the equation of the general case to assume the axis A to coincide with H. Angle s then becomes o, t is indeterminate for a symmetrical source, and angles e and c are identical.

We have for the fundamental equation of illumination,

$$E = \frac{I_e}{R^2} \cos i, \tag{1}$$

and the problem is to state E in terms of the constants H, a, b, d, and the variable c ($= e$). E is in foot-candles, I_e in candle-power and R in feet.

From fig. 1 we have the following relations.

$$D = H \tan d, \tag{2}$$

$$Z = H \tan c, \tag{3}$$

$$R = H \sec c, \tag{4}$$

$$L = H \sqrt{\tan^2 c - \tan^2 d}. \tag{5}$$

The plane of the right triangle whose sides are T, S, Q, is parallel to the reference plane, and H_0 is equal and parallel to H.

$$T = H \tan b, \tag{6}$$

$$S = H \tan b \sin a, \tag{7}$$

$$Q = H \tan b \cos a. \tag{8}$$

In the right triangle U, S, L — Q,

$$\begin{aligned} U^2 &= S^2 + (L - Q)^2 \\ &= H^2 \{ \tan^2 b + \tan^2 c - \tan^2 d \\ &\qquad - 2 \cos a \tan b \sqrt{\tan^2 c - \tan^2 d} \} \end{aligned} \tag{9}$$

In the triangle U, V, D,

$$\begin{aligned} V^2 &= D^2 + U^2 - 2DU \cos (90 - f), \\ &= D^2 + U^2 - 2DU \sin f, \\ &= D^2 + U^2 - 2DS, \\ &= H^2 \{ \tan^2 b + \tan^2 c - 2 \cos a \tan b \sqrt{\tan^2 c - \tan^2 d} \\ &\qquad - 2 \sin a \tan b \tan d \} \end{aligned} \tag{10}$$

In the triangle Y, R, V,

$$V^2 = Y^2 + R^2 - 2YR \cos i, \tag{11}$$

$$\cos i = \frac{Y^2 + R^2 - V^2}{2YR}. \qquad (12)$$

$$\frac{1 + \cos a \tan b \sqrt{\tan^2 c - \tan^2 d} + \sin a \tan b \tan d}{\sec b \sec c}. \qquad (13)$$

Substituting (4) and (13) in equation (1),

$$E = \frac{I}{H^2}\left\{\frac{1 + \cos a \tan b \sqrt{\tan^2 c - \tan^2 d} + \sin a \tan b \tan d}{\sec b \sec^3 c}\right\}. \qquad (14)$$

Equation (14) was derived for the special case of the axis of the source being perpendicular to the reference plane. If the axis is placed in the position A, as defined by the angles t and s, then e is the angle usually given in a polar distribution curve (the zero angle being on the axis) and enters the equation in place of the angle c just used.

Referring again to fig. 1, we have in the right triangle J, D—F, L—G,

$$J^2 = (L - G)^2 + (D - F)^2, \qquad (15)$$

and in the triangle R, A, J,

$$J^2 = R^2 + A^2 - 2RA \cos e, \qquad (16)$$

also

$$A = H \sec s, \qquad (17)$$

$$K = H \tan s, \qquad (18)$$

$$G = H \tan s \cos t, \qquad (19)$$

$$F = H \tan s \sin t. \qquad (20)$$

Equating (15) and (16),

$$(L - G)^2 + (D - F)^2 = R^2 + A^2 - 2RA \cos e.$$

Substituting from (2), (4), (5), (17), (19) and (20),

$$H^2 \left\{ \left(\sqrt{\tan^2 c - \tan^2 d} - \tan s \cos t\right)^2 + (\tan d - \tan s \sin t)^2 - \sec^2 c - \sec^2 s + 2 \sec c \sec s \cos e \right\} = 0.$$

Expanding,

$$\tan^2 c - \tan^2 d - 2 \tan s \cos t \sqrt{\tan^2 c - \tan^2 d} + \tan^2 s \cos^2 t$$
$$+ \tan^2 d - 2 \tan d \tan s \sin t + \tan^2 s \sin^2 t - \sec^2 c - \sec^2 s$$
$$+ 2 \sec c \sec s \cos e = 0,$$

$$1 + \tan d \tan s \sin t - \sec c \sec s \cos e =$$
$$- \tan s \cos t \sqrt{\tan^2 c - \tan^2 d}. \qquad (21)$$

Squaring both sides to eliminate the radical and substituting $\sqrt{\sec^2 c - \sec^2 d}$ for $\sqrt{\tan^2 c - \tan^2 d}$,

$$1 + \tan^2 d \tan^2 s \sin^2 t - \sec^2 c \sec^2 s \cos^2 e + 2 \tan d \tan s \sin t$$
$$- 2 \sec c \sec s \cos e - 2 \sec c \tan d \tan s \sec s \sin t \cos e$$
$$= \tan^2 s \cos^2 t \sec^2 c - \tan^2 s \cos^2 t \cdot \sec^2 d.$$

Rearranging, and expressing as a quadratic in sec c,

$$\sec^2 c\,(\sec^2 s \cos^2 e - \tan^2 s \cos^2 t)$$
$$- 2 \sec c\,(\sec s \cos e + \tan d \tan s \sec s \sin t \cos e)$$
$$- (1 - 2 \tan d \tan s \sin t + \tan^2 d \tan^2 s + \tan^2 s \cos^2 t) = 0. \quad (22)$$

This quadratic is of the form $p \sec^2 + q \sec c + r = 0$,

and the roots are

$$\frac{-q \pm \sqrt{q^2 - 4pr}}{2r}. \quad (23)$$

Form (22) and (23),

$$q^2 - 4pr = 4 \{ \sec^2 s \cos^2 e + \tan^2 d \tan^2 s \sec^2 s \sin^2 t \cos^2 e$$
$$+ 2 \tan d \tan s \sec^2 s \sin t \cos^2 e - \sec^2 s \cos^2 e$$
$$+ \tan^2 s \cos^2 t - 2 \tan d \tan s \sec^2 s \sin t \cos^2 e$$
$$+ 2 \tan d \tan^3 s \sin t \cos^2 t$$
$$- \tan^2 d \tan^2 s \sec^2 s \cos^2 e + \tan^2 d \tan^4 s \cos^2 t$$
$$- \tan^2 s \sec^2 s \cos^2 t \cos^2 e + \tan^4 s \cos^4 t \}$$
$$= 4 \tan^2 s \cos^2 t \{ \sec^2 s \sec^2 d \sin^2 e - (\tan d - \tan s \sin t)^2 \} \quad (24)$$

Substituting from (22) and (24) in (23),

$$\sec c = \frac{\{ 2 \sec s \cos e(1 + \tan d \tan s \sin t) \pm 2 \tan s \cos t \sqrt{\sec^2 s \sec^2 d \sin^2 e - (\tan d - \tan s \sin t)} \}}{2(\sec^2 s \cos^2 e - \tan^2 s \cos^2 t)}. \quad (25)$$

This expression for sec c may be substituted in both numerator and denominator of (14) after replacing $\sqrt{\tan^2 c - \tan^2 d}$ by its equivalent $\sqrt{\sec^2 c - \sec^2 d}$.

The equation of the general case of illumination along a straight line by a symmetrical source is

$$E = \frac{I_e}{H^2}\left\{\frac{1 + \cos a \tan b\sqrt{\sec^2 c - \sec^2 d} - \sin a \tan b \tan d}{\sec b \sec^3 c}\right\} \qquad (26)$$

where

$$\sec c = \frac{\left\{\sec s \cos e(1 + \tan d \tan s \sin t) \pm \tan s \cos t\sqrt{\sec^2 s \sec^2 d \sin^2 e - (\tan d - \tan s \sin t)^2}\right\}}{\sec^2 s \cos^2 e - \tan^2 s \cos^2 t} \qquad (27)$$

and I_e is the candle-power at the angle e on the photometric curve.

The equation for L, for a radical line is

$$L = H \tan c, \qquad (28)$$

or for a non-radial line, measuring from the intersection of L and D,

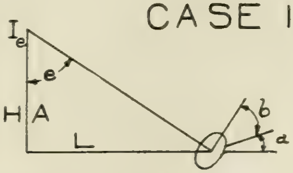
$$L = H\sqrt{\sec^2 c - \sec^2 d}, \qquad (29)$$

the above expression for sec c always being used.

Counterclockwise rotation is taken as the positive direction in measuring the angles *a, b, c, d, s* and *t*. The distribution of light is the same in every meridian plane, hence I_{-e} is always equal to I_{+e}, and functions of e, such as $\cos^2 e \sin e$, $\sin^3 e$, etc., must always be given a positive value. Thus in case 1, equation 1-2, the value of $\cos^2 c \sin c$ changes from plus to minus, as c passes through zero. This does not mean that the equation reduces to an absurdity at this point by indicating negative illumination. The meaning is that after passing zero degrees the *negative side* of the test plate, or elemental surface *ds* is illuminated.

The following equations are obtained by substitution in equations (26), (27), (28) and (29). They are classified, first, according to the position of the source, second, according to the line of illumination (radial or non-radial) and third, according to the position of the surface *ds*. Each equation is divided into a constant and a variable factor. The reason for this division will appear later in the discussion of the graphic methods given in the second part of this paper.

CASE 1



$s = 0$

$t = \text{Indeterminate}$

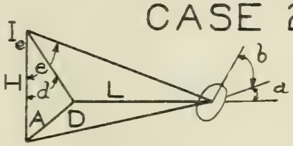
$d = 0$

$$E = K\frac{I_e}{H^2}f(e)$$

$$L = H\tan e$$

NO	a	b	K	f(e)	RULE
1-1	0	0	1	$\cos^3 e$	1
1-2	0	90	1	$\cos^2 e \sin e$	5
1-3	NORMAL		1	$\cos^2 e$	2,3
1-4	0	b_1	1	$\cos^2 e \cos(e - b_1)$	4
1-5	90	b_1	$\cos b_1$	$\cos^3 e$	1

CASE 2



$s = 0$

$t = \text{Indeterminate}$

$d = d_1$

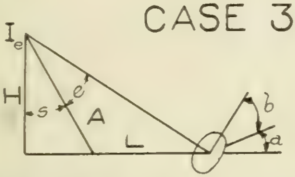
$$E = K\frac{I_e}{H^2}f(e)$$

$$L = H\sqrt{\tan^2 e - \tan^2 d_1}$$

NO	a	b	K	f(e)	RULE
2-1	0	0	1	$\cos^3 e$	1
2-2	0	90	1	$\cos^3 e\sqrt{\tan^2 e - \tan^2 d_1}$	–
2-3	90	90	$\tan^2 d_1$	$\cos^3 e$	1
2-4	*	90	1 *Max. Vertical Illumination	$\cos^2 e \sin e$	5
2-5	NORMAL		1	$\cos^2 e$	2,3
2-6	0	b_1	$\cos b_1$	$\dfrac{1 + \tan b_1\sqrt{\tan^2 e - \tan^2 d_1}}{\sec^3 e}$	–
2-7	90	b_1	$\cos(d_1 - b_1)$	$\cos^2 e$	2,3

Calculation formulæ—cases 1 and 2.

CASE 3



$s = s_1$

$t = 0$

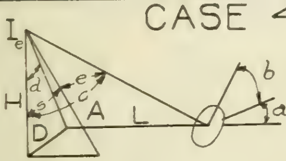
$d = 0$

$E = K \frac{I_e}{H^2} f(e)$

$L = H \tan(e + s_1)$

NO	a	b	K	f(e)	RULE
3-1	0	0	1	$\cos^3(e+s_1)$	6
3-2	0	90	1	$\cos^2(e+s_1)\sin(e+s_1)$	8
3-3	NORMAL		1	$\cos^2(e+s_1)$	7
3-4	0	b_1	1	$\cos^2(e+s_1)\cos(e+s_1-b_1)$	9
3-5	90	b_1	$\cos b_1$	$\cos^3(e+s_1)$	6

CASE 4



$s = s_1$

$t = 0$

$d = d_1$

$E = K \frac{I_e}{H^2} f(e)$

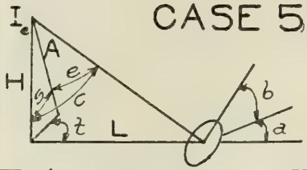
$L = H\sqrt{\sec^2 c - \sec^2 d_1}$

$$\sec c = \frac{\cos s_1 \cos e \pm \sin s_1 \cos s_1 \tan d_1 \sqrt{\sec^2 s_1 \operatorname{cosec}^2 d_1 \sin^2 e - 1}}{\cos^2 e - \sin^2 s_1}$$

NO	a	b	K	f(e)	RULE
4-1	0	0	1	$\cos^3 c$	—
4-2	0	90	1	$\cos^3 c\sqrt{\sec^2 c - \sec^2 d_1}$	—
4-3	90	90	$\tan d_1$	$\cos^3 c$	—
4-4	*	90	1 *Max Vertical Illumination	$\cos^2 c \sin c$	—
4-5	NORMAL		1	$\cos^2 c$	—
4-6	0	b_1	$\cos b_1$	$\frac{1 + \tan b_1\sqrt{\sec^2 c - \sec^2 d_1}}{\sec^3 c}$	—
4-7	90	b_1	$\cos(d_1 - b_1)$	$\cos^2 c$	—

Calculation formulæ—cases 3 and 4.

CASE 5



$s = s_1$

$t = 90°$

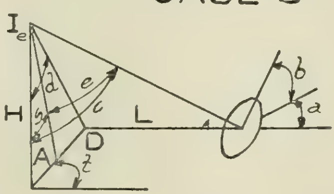
$d = 0$

$$E = K\frac{I_e}{H^2}f(e)$$

$$L = H\cos s\sqrt{\tan^2 e - \tan^2 s_1}$$

NO	a	b	K	f(e)	RULE
5-1	0	0	$\sec^3 s_1$	$\cos^3 e$	1
5-2	0	90	$\sec^3 s_1$	$\cos^3 e\sqrt{\tan^2 e - \tan^2 s_1}$	–
5-3	NORMAL		$\sec^2 s_1$	$\cos^2 e$	2,3
5-4	0	b_1	$\cos b_1 \sec^3 s_1$	$\frac{1+\tan b_1\sqrt{\cos^2 s_1 \sec^2 e - 1}}{\sec^3 e}$	–
5-5	90	b_1	$\sec^3 s_1 \cos b_1$	$\cos^3 e$	1

CASE 6



$s = s_1$

$t = 90°$

$d = d_1$

$$E = K\frac{I_e}{H^2}f(e)$$

$$K_1 = \frac{\sec s_1}{1 + \tan d_1 \tan s_1}$$

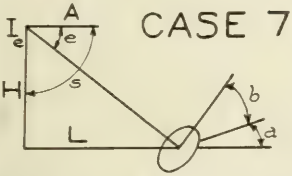
$$L = \frac{H}{K_1}\sqrt{\tan^2 e + 1 - \left(\frac{\sec d_1}{K_1}\right)^2}$$

$$\sec c = K_1 \sec e$$

NO	a	b	K	f(e)	RULE
6-1	0	0	K_1^3	$\cos^3 e$	1
6-2	0	90	K_1^3	$\frac{\sqrt{K_1^2 \sec^2 e - \sec^2 d_1}}{\sec^3 e}$	–
6-3	90	90	$K_1^3 \tan d_1$	$\cos^3 e$	1
6-4	NORMAL		K_1^2	$\cos^2 e$	2,3
6-5	0	b_1	$K_1^3 \cos b_1$	$\frac{1+\tan b_1\sqrt{K_1^2 \sec^2 e - \sec^2 d_1}}{\sec^3 e}$	–
6-6	90	b_1	$K_1^3 \cos b_1 (1+\tan b_1 \tan d_1)$	$\cos^3 e$	1

Calculation formulæ—cases 5 and 6.

CASE 7



$s = 90°$

$t = 0$

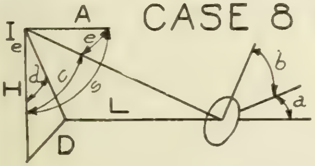
$d = 0$

$$E = K\frac{I_e}{H^2} f(e)$$

$$L = H \cot e$$

NO	a	b	K	f(e)	RULE
7-1	0	0	1	$\sin^3 e$	10
7-2	0	90	1	$\cos e \sin^2 e$	13
7-3	NORMAL		1	$\sin^2 e$	11
7-4	0	b_1	1	$\sin^2 e \sin(e + b_1)$	12
7-5	90	b_1	$\cos b_1$	$\sin^3 e$	10

CASE 8



$s = 90°$

$t = 0$

$d = d_1$

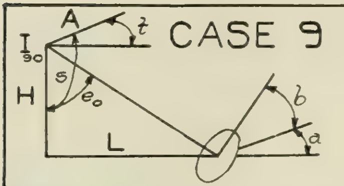
$$E = K\frac{I_e}{H^2} f(e)$$

$$L = H \sec d_1 \cot e$$

NO	a	b	K	f(e)	RULE
8-1	0	0	$\cos^3 d_1$	$\sin^3 e$	10
8-2	0	90	$\cos^2 d_1$	$\cos e \sin^2 e$	13
8-3	90	90	$\sin d_1 \cos^2 d_1$	$\sin^3 e$	10
8-4	NORMAL		$\cos^2 d_1$	$\sin^2 e$	11
8-5	0	b_1	$\cos b_1 \cos^3 d_1$	$\sin^3 e + \tan b_1 \sec d_1 \cos e \sin^2 e$	10 & 11
8-6	90	b_1	$\frac{\cos(d_1 - b_1)}{\sec^2 d_1}$	$\sin^3 e$	10

Calculation formulæ—cases 7 and 8.

CASE 9



$s = 90^\circ$

$t = 90^\circ$

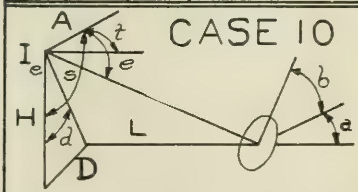
$d = 0$

$E = \frac{K}{H^2} f(e_o)$

$L = H \tan e_o$

NO	a	b	K	f(e)	RULE
9-1	0	0	I_{90}	$\cos^3 e_o$	1
9-2	0	90	I_{90}	$\cos^2 e_o \sin e_o$	5
9-3	NORMAL		I_{90}	$\cos^2 e_o$	2,3
9-4	0	b_1	I_{90}	$\cos^2 e_o \cos(e_o - b_1)$	4
9-5	90	b_1	I_{90}	$\cos^3 e_o$	1

CASE 10



$s = 90^\circ$

$t = 90^\circ$

$d = d_1$

$E = K \frac{I_e}{H^2} f(e)$

$L = H\sqrt{\tan^2 d_1 \tan^2 e - 1}$

NO	a	b	K	f(e)	RULE
10-1	0	0	$\cot^3 d_1$	$\cos^3 e$	1
10-2	0	90	$\cot^3 d_1$	$\cos^3 e\sqrt{\tan^2 d_1 \tan^2 e - 1}$	-
10-3	90	90	$\cot^2 d_1$	$\cos^3 e$	1
10-4	NORMAL		$\cot^2 d_1$	$\cos^2 e$	2,3
10-5	0	b_1	$\frac{1 + \tan b_1 \tan d_1}{\sec b_1 \sec^3 d_1}$	$\cos^3 e$	1
10-6	90	b_1	$\cos^2 d_1 \sin(d_1 + b_1)$	$\cos^3 e$	1

Calculation formulæ—cases 9 and 10,

SECTION II.

EQUIPMENT.

The graphic illumination chart herein described requires for its use a draughting board, T-square and a 12 inch triangle. No calculations are required except in the cases where the constant K is not unity, and then a single calculation suffices for a set of curves.

METHODS OF CALCULATING AND TABULATING.

The process of calculating an illumination curve is always divided into two distinct steps. The first step is the calculation of the foot-candles for the given values of I_e, $f(e)$, and H. The second step is the calculation of the distance along the line of illumination at which the ray strikes the reading plane.

The two steps are

$$E = K'I_e f(e),$$
$$L = K''F(e),$$

where e is the parameter.

I_e is also a function of the angle e, but in commercial testing the nature of the function is seldom known.

There are two ways of tabulating $K'f(e)$ and $K''F(e)$ that are in general use. In the one method the distances and illumination constants are tabulated for every five or ten degrees. This gives an uneven spacing along the line of illumination, but has the advantage of using the photometric curve at the points taken in the photometric test, and thus largely eliminating differences of judgment in drawing the photometric curve through these points. In the other method the distances and illumination constants are tabulated at fixed points along the line of illumination. The value of I_e are read from the photometric curve, and thus are dependent upon the accuracy of the latter.

The graphic method given here uses the test points on the photometric curve, with as many intermediate points as are necessary to accurately determine the illumination curve. From twelve to thirty points on one curve may be determined, according to requirements.

TABULATION OF HEIGHTS AND SCALES.

In fig. 2 is shown a tabulation of heights, distance scales, candle-power scales, and foot-candle scales. The use of this tabulation is illustrated in figs. 5 to 11 by underscoring the data used.

As an example, let us take the case of a source having a maximum intensity of 450 candle-power. Horizontal illumination curves are required for heights of 15, 20 and 25 feet. In fig. 2 these heights are found on the horizontal line marked group 5. Immediately to the left, under the heading Distance Scales is found $\frac{Z}{10}$. At the bottom of the chart are three scales marked X, Y, Z at their unit divisions. The lower scale in this case represents 10 feet at Z. This scale is not needed until the illumination curves are drawn; then it may be used to draw the web over the curves.

At the head of the column containing 15 feet (4.58 m.) is

REQUEST________________ DRAWN BY________________
FROM________________ CHECKED BY________________
C-________________ TRACED BY________________
DATE________________ CHECKED BY________________

GROUP	DISTANCE SCALE	HEIGHT OF LAMP, CORRESPONDING LETTER OF ILLUMINATION CURVE AND TANGENT SCALE								CANDLE-POWER AT I ON WEB AND CORRESPONDING FOOT-CANDLES AT M.P.R.__ ON FOOT-CANDLE SCALES										
		A	B	C	D	E	F	G	H	I/100	I/125	I/150	I/200	I/250	I/300	I/400	I/500	I/600	I/750	I/800
1	X/5	3	3.5	4	4.5	5	5.5	6	6.5	U 5	W 5	P 10	U 10	W 10	P 20	U 20	W 20	M 50	P 50	U 40
2	X/10	6	7	8	9	10	11	12	13	W 1	R 2	T 2	W 2	W 2.5	P 5	U 5	W 5	P 10	T 10	U 10
3	Y/10	9	10.5	12	13.5	15	16.5	18	19.5	V 0.5	N 1	S 1	V 1	N 2-	S 2	V 2	N 4	S 4	S 5	V 4
4	X/20	12	14	16	18	20	22	24	26	W 0.25	R 0.5	T 0.5	W 0.5	R 1	T 1	W 1	R 2	T 2	T 2.5	W 2
5	Z/10	15	17.5	20	22.5	25	27.5	30	32.5	U 0.2	W 0.2	M 0.5	U 0.4	U 0.5	M 1	U 0.8	U 1	M 2	P 2	U 1.6
6	Y/20	18	21	24	27	30	33	36	39	N 0.2	N 0.25	S 0.25	N 0.4	N 0.5	S 0.5	V 0.5	N 1	S 1	N 1.5	V 1
7	X/40	24	28	32	36	40	44	48	52	R 0.1	R 0.125	T 0.125	R 0.2	R 0.25	T 0.25	W 0.25	R 0.5	T 0.5	R 0.75	W 0.5
8	Z/20	30	35	40	45	50	55	60	65	U 0.05	W 0.05	P 0.1	U 0.1	W 0.1	P 0.2	U 0.2	W 0.2	M 0.5	P 0.5	U 0.4

APPROVED________________________
ILLUMINATING ENGINEER

Fig. 2.

found the letter A. This refers to the standard curve (in three sections) that is found on the right of the chart under the candle-power web. Curve A is used for a height of 15 feet (4.58 m.), C for 20 feet (6.1 m.), and E for 25 feet (7.63 m.).

In selecting a scale to plot the photometric curve, it is usually best to choose as large a scale as possible in order to obtain the most accurate results. Thus, in the present example, make I on the candle-power web equal to 50. At the top of the fourth column from the right, fig. 2, is found $\frac{I}{500}$. Under this heading, and on the line of group 5 is found $\frac{U}{1}$. Moving the deci-

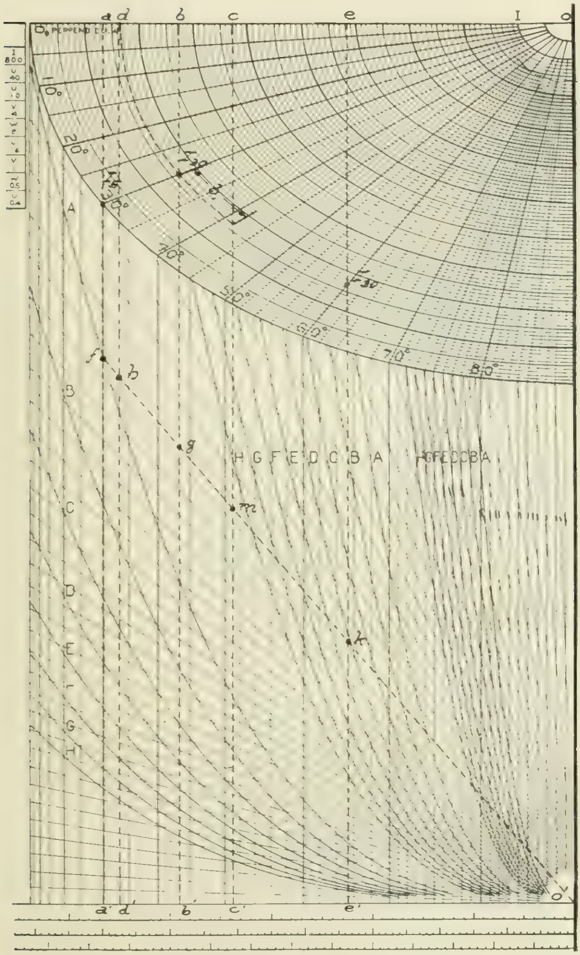


Fig. 3.

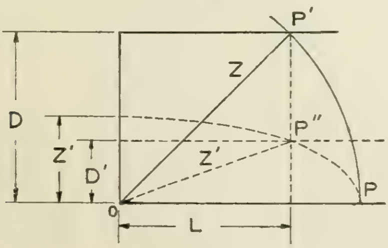


Fig. 4.

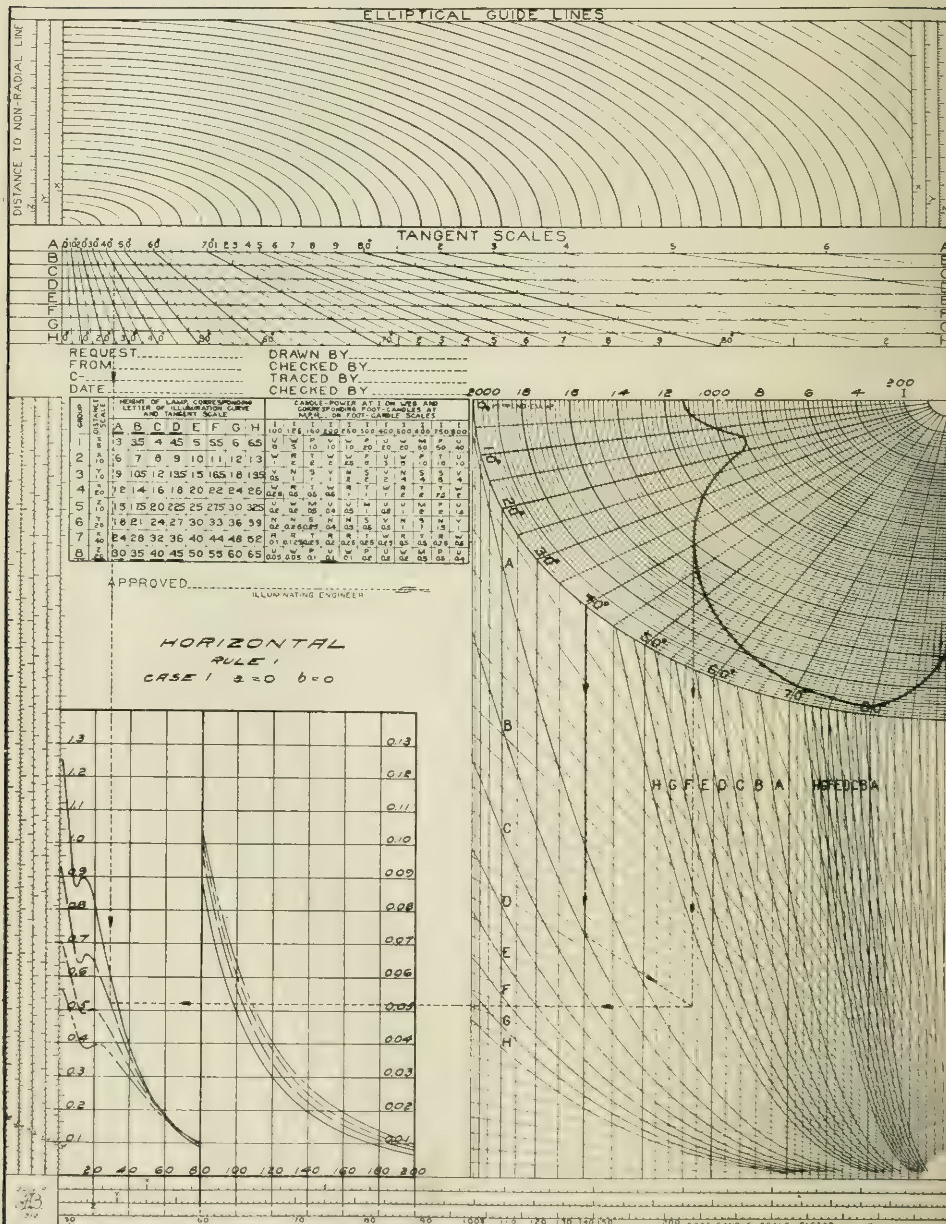

ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
ILLUMINATING ENGINEER
HORIZONTAL
RULE 1
CASE 1 a=0 b=0
FOOT-CANDLE SCALE FACTOR

Fig. 5.

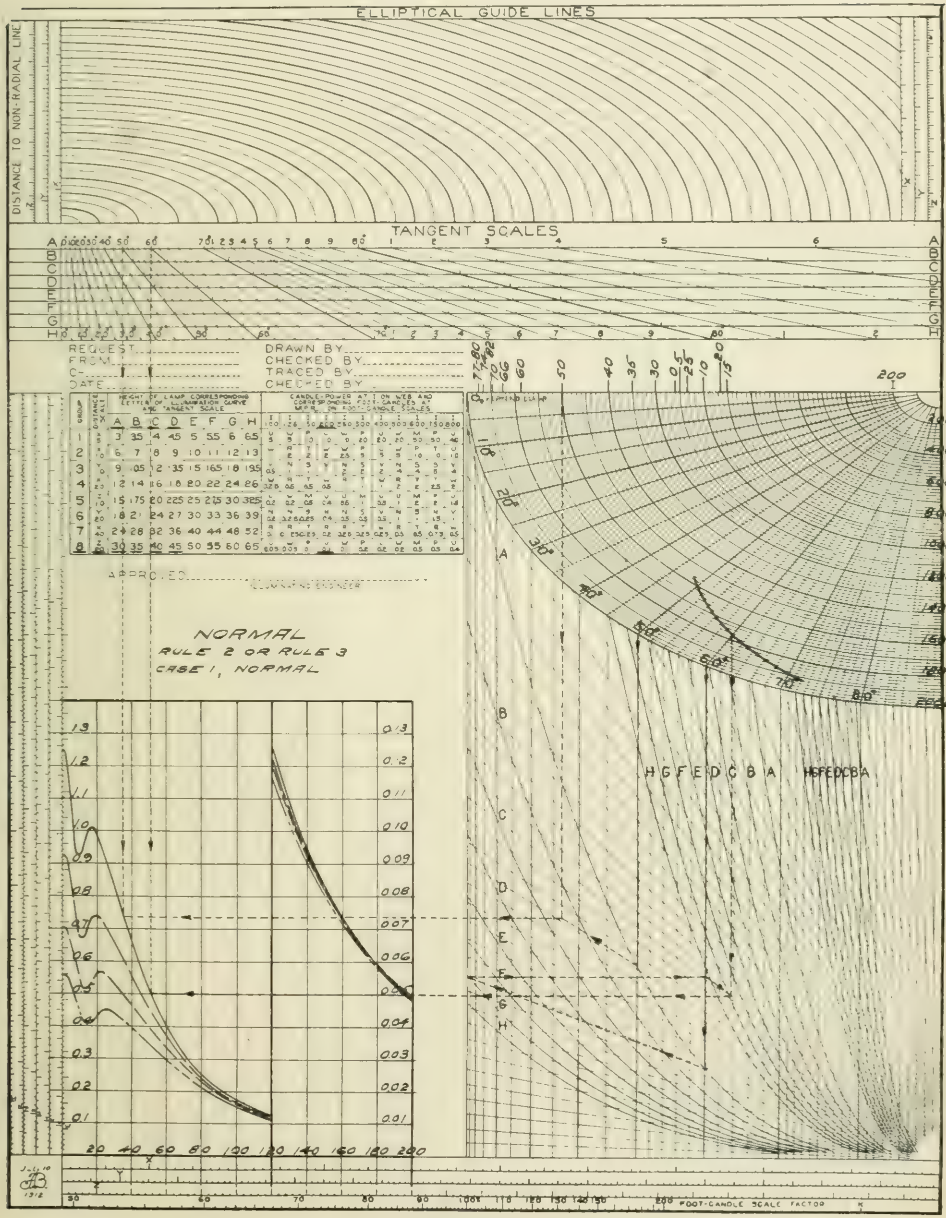

ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
ILLUMINATING ENGINEER
NORMAL
RULE 2 OR RULE 3
CASE 1, NORMAL
FOOT-CANDLE SCALE FACTOR

Fig. 6.

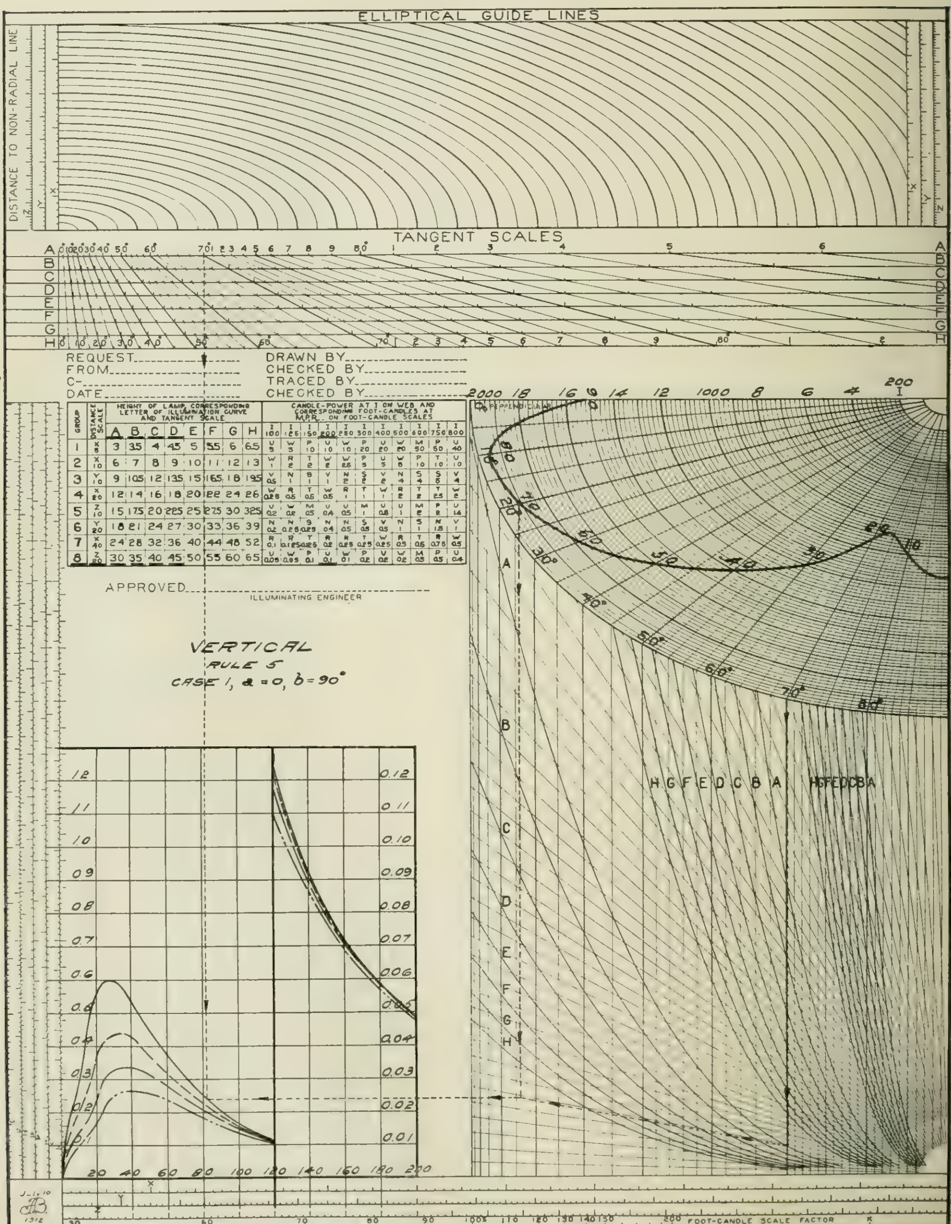

ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
C-
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
ILLUMINATING ENGINEER
VERTICAL
RULE 5
CASE 1, a = 0, b = 90°
FOOT-CANDLE SCALE FACTOR

Fig. 7

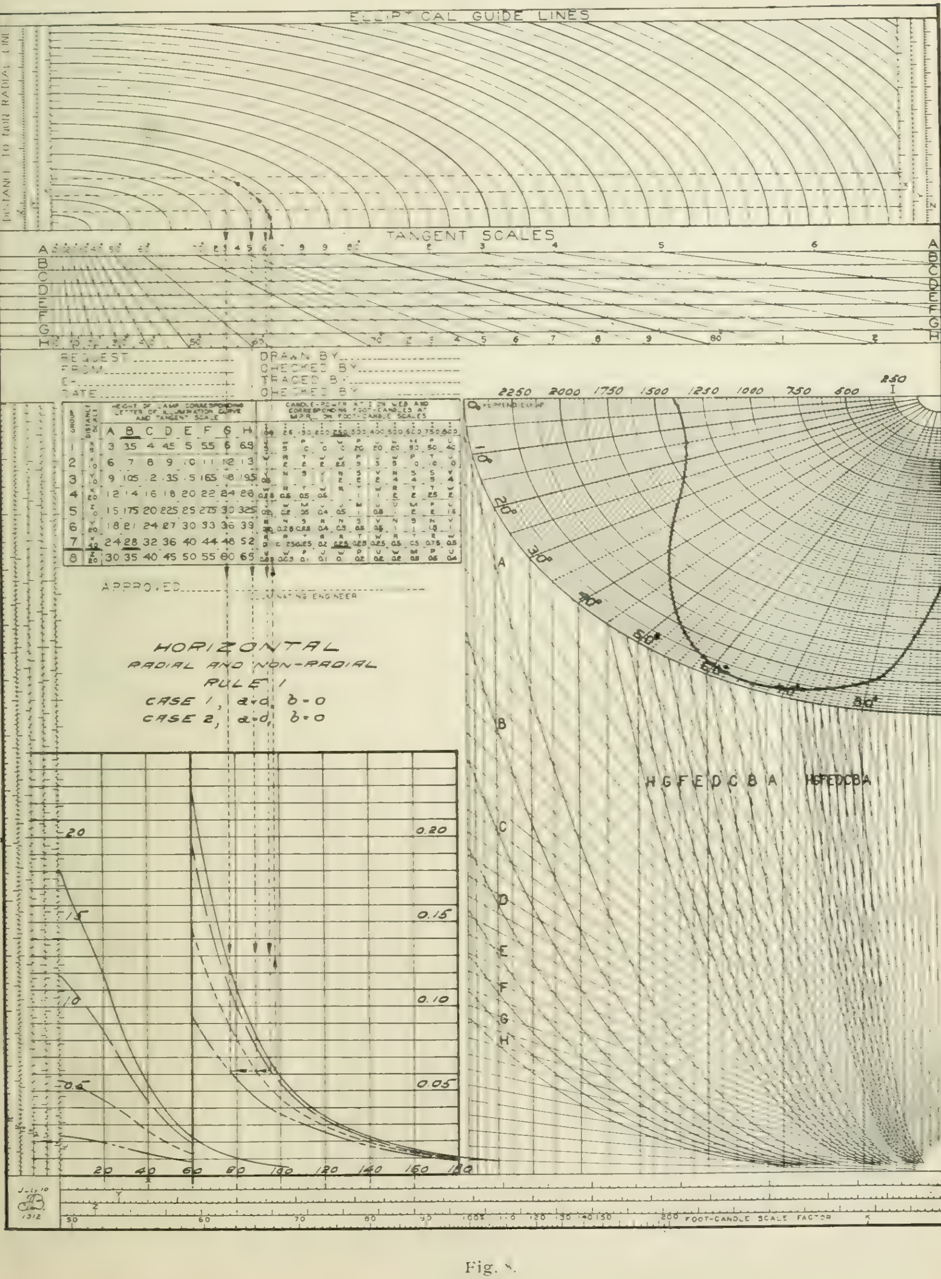

ELLIPTICAL GUIDE LINES
TANGENT SCALES
REQUEST
FROM
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
HORIZONTAL
RADIAL AND NON-RADIAL
RULE 1
CASE 1, a=d, b=0
CASE 2, a=d, b=0
2250 2000 1750 1500 1250 1000 750 500 250
HGFEDCBA
FOOT-CANDLE SCALE FACTOR

Fig. 8

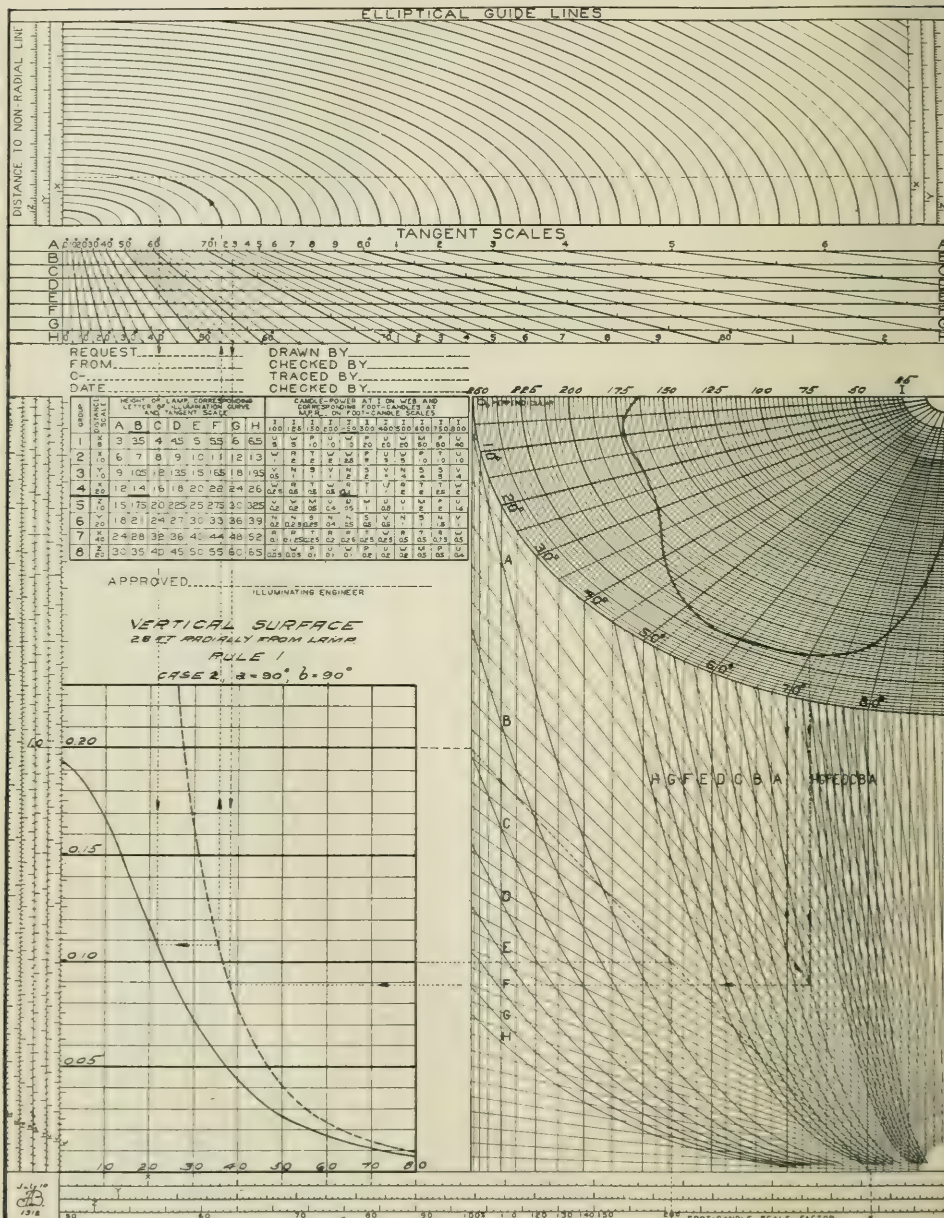

ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
C-
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
ILLUMINATING ENGINEER
VERTICAL SURFACE
28 FT RADIALLY FROM LAMP
RULE 1
CASE 2, a = 90°, b = 90°
FOOT-CANDLE SCALE FACTOR

Fig. 9.

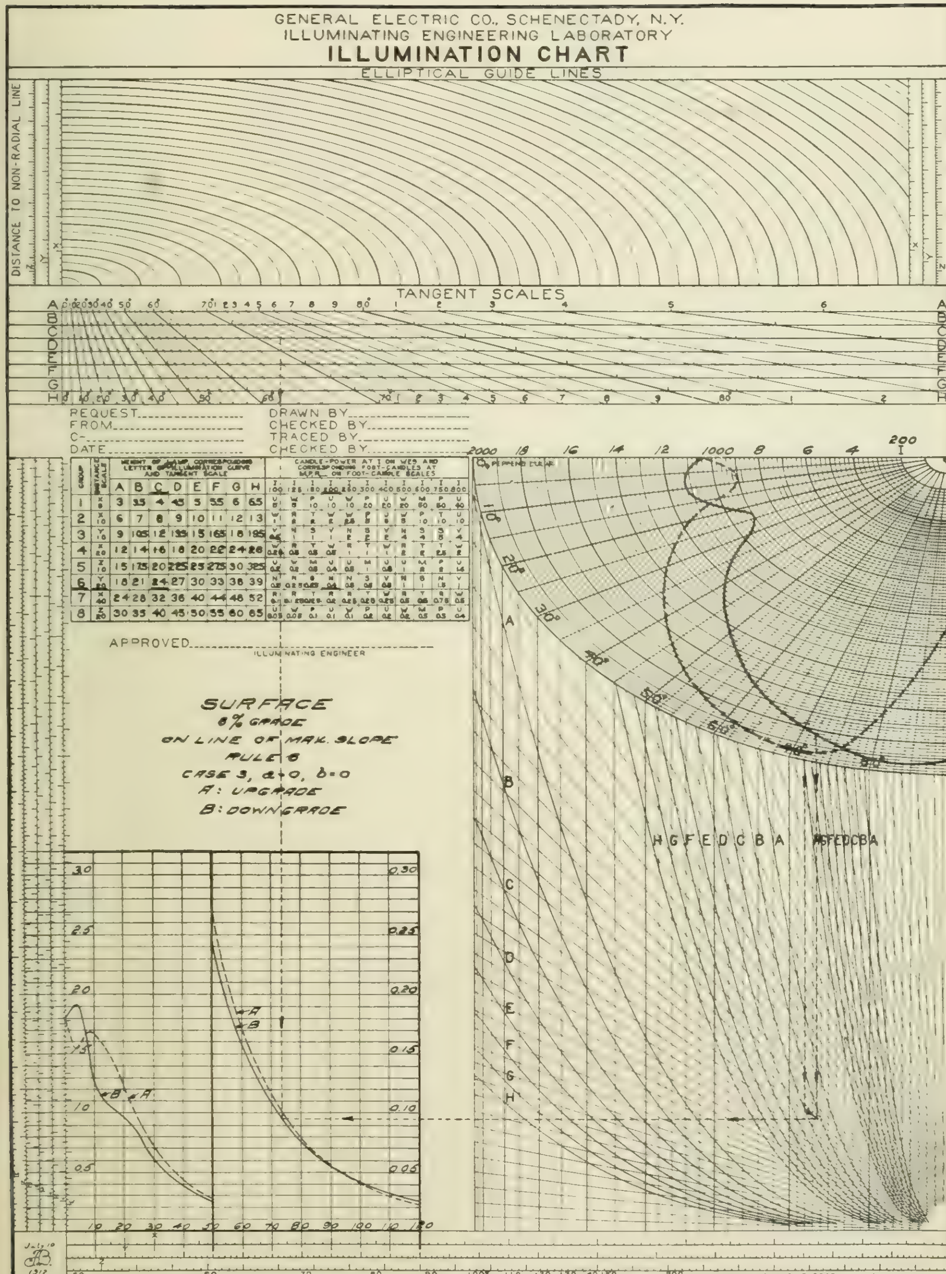

GENERAL ELECTRIC CO., SCHENECTADY, N.Y.
ILLUMINATING ENGINEERING LABORATORY
ILLUMINATION CHART
ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
C-
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
APPROVED
ILLUMINATING ENGINEER
SURFACE
6% GRADE
ON LINE OF MAX. SLOPE
RULE 6
CASE 3, a=0, b=0
A: UPGRADE
B: DOWNGRADE
FOOT-CANDLE SCALE FACTOR

Fig. 10.

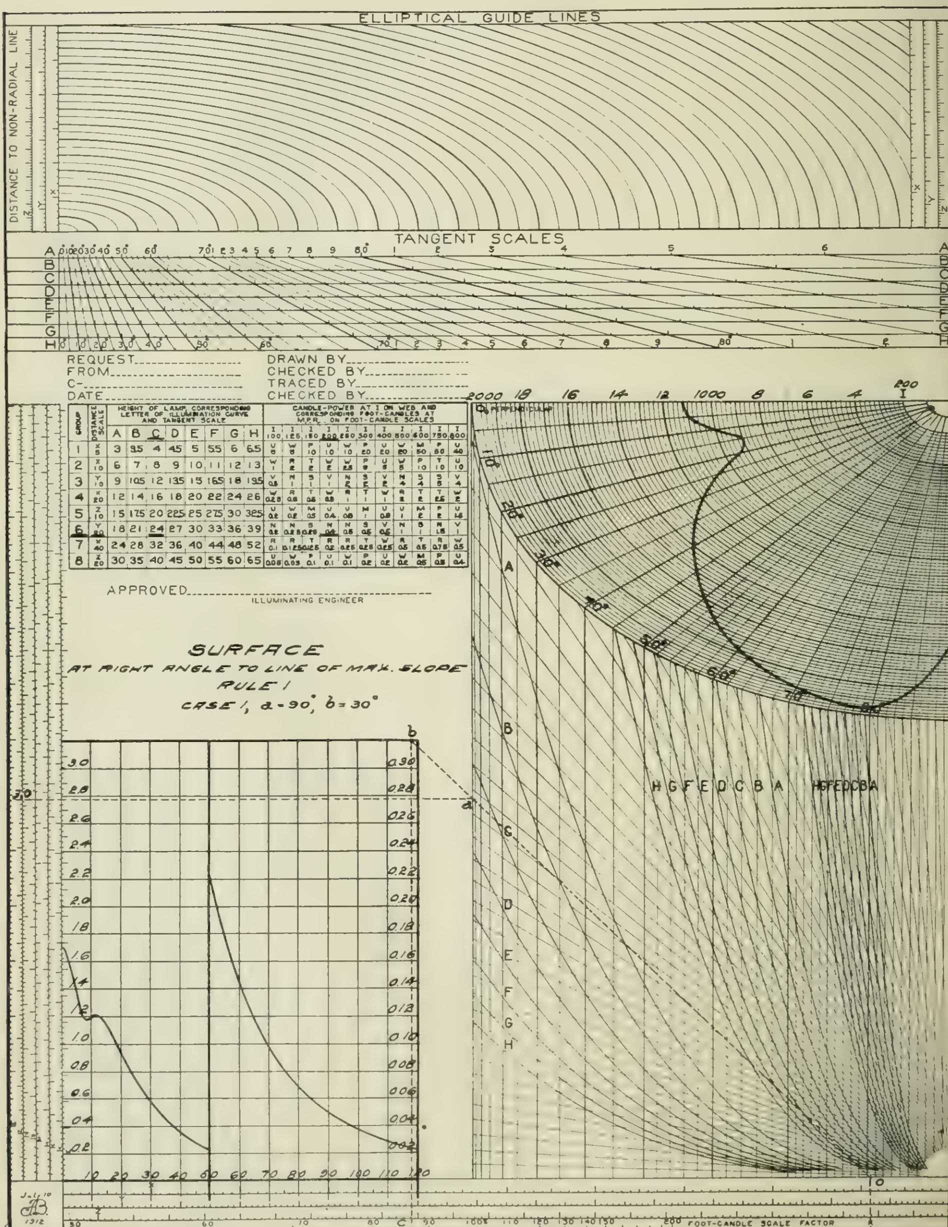

ELLIPTICAL GUIDE LINES
DISTANCE TO NON-RADIAL LINE
TANGENT SCALES
REQUEST
FROM
C-
DATE
DRAWN BY
CHECKED BY
TRACED BY
CHECKED BY
HEIGHT OF LAMP CORRESPONDING LETTER OF ILLUMINATION CURVE AND TANGENT SCALE
CANDLE-POWER AT I ON WEB AND CORRESPONDING FOOT-CANDLES AT M.P.R. ON FOOT-CANDLE SCALES
GROUP
DISTANCE SCALE
A B C D E F G H
1 3 3.5 4 4.5 5 5.5 6 6.5
2 6 7 8 9 10 11 12 13
3 9 10.5 12 13.5 15 16.5 18 19.5
4 12 14 16 18 20 22 24 26
5 15 17.5 20 22.5 25 27.5 30 32.5
6 18 21 24 27 30 33 36 39
7 24 28 32 36 40 44 48 52
8 30 35 40 45 50 55 60 65
APPROVED
ILLUMINATING ENGINEER
SURFACE
AT RIGHT ANGLE TO LINE OF MAX. SLOPE
RULE 1
CASE 1, a = 90°, b = 30°
PERPENDICULAR
FOOT-CANDLE SCALE FACTOR

Fig. 11.

mal point one place to the left we have $\frac{I}{50}$ (candle-power) and $\frac{U}{0.1}$ (foot-candles). Along the left edge of the chart are nine foot-candle scales marked M, N, P, —W at their unit divisions. The division marked U is 0.1 foot-candle. This scale, like the distance scale, is not used until the illumination curves are finished.

CANDLE-POWER WEB AND STANDARD CURVES.

A review of the equation given in cases 1 to 10 will show that in a majority of the equations the variable $f(e)$ is of some simple trigonometric form, such as $\cos^3 e$, $\cos^2 e$, $\cos^2 e \sin e$, etc. These functions are in most cases either cubes ($\cos^3 e$), or products of a square and a first power ($\cos^2 e \sin e$), and the cubes may also be considered as the product of a square and a first power ($\cos^2 e \cos e$). Thus the variables are seen to be alike in having $\cos^2 e$ in common, and to differ from one another by a first power ($\cos e$, 1, $\sin e$, etc.).

The graphic method here given is based largely on the above relations, the photometric curve being rotated on the web to give horizontal projection at the various angles, which are proportional to $\cos e$, 1, $\sin e$, etc.

In fig. 3 let I_{30} be the intensity or a photometric curve at 30°. From the similar triangles O, I_{30}, b, and O, I_s, a, we have

$$\frac{I_{30}}{I_s} = \frac{Ob}{Oa},$$

$$I_{30} = I_s \frac{Ob}{Oa},$$

where I_s is the intensity at the outer edge of the web.

Also in triangles O′, b', g and O′, a', f,

$$\frac{O'b'}{O'a'} = \frac{b'g}{a'f},$$

$$b'g = a'f \frac{O'b'}{O'a'}.$$

But

$$\frac{O'b'}{O'a'} = \frac{Ob}{Oa}.$$

Therefore

$$b'g = a'f \frac{I_{30}}{I_s}.$$

By construction $$a'f = \frac{I_s \cos^3 30}{H_A^2}.$$

Hence $$b'g = \frac{I_{30} \cos^3 30}{H_A^2},$$

that is, the height $b'g$ measured by the proper scale, represents the horizontal illumination (case 1, $a=o$, $b=o$), due to an intensity I_{30} at 30^0, the source being A feet above the reading or reference plane.

If, in place of plotting the intensity I_{30} on the radial marked 30^0 we plot it at d, fig. 3, on the zero degree radial, then we have the following relations.

$$\frac{Od}{Ob} = \frac{1}{\cos 30},$$

as by construction the horizontal projection of the radials marked 0^0, 10^0, 20^0, etc., are in proportion *cos* 0^0, *cos* 10^0, *cos* 20^0, etc.

$$\frac{Od}{Ob} = \frac{O'd'}{O'b'} \quad \frac{d'h}{b'g},$$

therefore

$$\frac{d'h}{b'g} = \frac{1}{\cos 30},$$

and

$$d'h = b'g \frac{1}{\cos 30} = \frac{I_{30}}{H_A^2} \frac{\cos^3 30}{\cos 30} = \frac{I_{30}}{H_A^2} \cos^2 30.$$

The right hand member is the expression for normal illumination corresponding to a candle-power I_{30} at 30^0, the source being A feet above the reading plane.

Let the entire photometric curve be rotated counterclockwise through b_1 degrees so that I_{30} falls at $(30 + b_1)$ degrees on the web. In fig. 3

$$\frac{Oc}{Ob} = \frac{\cos (30 + b_1)}{\cos 30},$$

$$\frac{Oc}{Ob} = \frac{O'c'}{O'b'} = \frac{c'm}{b'g},$$

$$c'm = b'g \frac{\cos (30 + b_1)}{\cos 30} = \frac{I_{30}}{H_A^2} \cos^2 30 \cos (30 + b_1).$$

This is the equation given in case 1, $a = 0$, $b = -b_1$.

As final example let us plot the photometric curve in the reverse direction with 0^0 on the curve at 90^0 on the web, etc. I_{30} now falls on the 60^0 radial ($90^0 - 30^0 = 60^0$).

From fig. 3

$$\frac{Oe}{Ob} = \frac{O'e'}{O'b'} = \frac{\cos 60}{\cos 30} = \frac{e'k}{b'g},$$

$$e'k = b'g \frac{\cos 60}{\cos 30} = \frac{I_{30}}{H_A^2} \frac{\cos^3 30 \cos 60}{\cos 30}$$

$$= \frac{I_{30}}{H_A^2} \cos^2 30 \sin 30.$$

This is the equation for vertical illumination along a radial line. See case 1, $a = o$, $b = 90$.

The angles printed on the web are measured from the perpendicular to the reference plane, fig. 1, and should not be confused with the angles of the photometric curve.

TANGENT SCALES.

Near the top of the chart are eight horizontal scales marked A, B, C,—H. By means of these scales the distance L along the line of illumination is determined. Each scale is used with the standard curve having the same letter, and the angles marked on these scales correspond to the angles on the candle-power web. Thus, in fig. 5, the operations are indicated for determining the horizontal illumination at 40° from the vertical axis of the source, the source being 35 feet (10.7 m.) above the reading (or reference) plane. Standard curve B and tangent scale B are used, and the 40° mark on tangent scale B corresponds to the 40° point on the candle-power web from which the construction was started.

The tangent scales, when used alone, give the distance L along a radial line of illumination and when used with the elliptical guide lines at the top of the chart, give the distance L along a non-radial line of illumination.

ELLIPTICAL GUIDE LINES.

At either end of the elliptical guide lines are three stub scales market X, Y, and Z at their unit division. X, Y, and Z have the same values as on the three scales at the bottom of the chart, and like the latter, have their values determined in any particular case by means of the tabulation given in fig. 2.

If a symmetrical source is placed with its axis perpendicular to the reference plane, then the illumination is the same at every

point in the plane located in a circle about the axis. Let the radius of this circle be Z, and let it cross a given line of illumination located D feet from the foot of the axis, as shown in fig. 4.

Then the illumination on the plane is the same at P and P′;

$$L = \sqrt{Z^2 - D^2}.$$
$$Z = \sqrt{L^2 + D^2}.$$

It is common practice to use the above construction in calculating average illumination, etc., for lighting plans. An illumination curve is calculated for the radial line, and the point P′ is located by measurement on the lighting plan.

If in place of laying off D and Z to the same scale we lay off D to a scale 0.4 as large as that used for Z, then the arc PP′ becomes PP″, an arc of an ellipse whose major axis is Z, minor axis Z′ and eccentricity 0.4. The line of illumination, laid off to the reduced scale passes through P″, and the projections of OP′ and OP″, on the radial line of illumination are identical. Thus the choice of scales for distances L and D becomes solely a question of convenience, or accuracy. In working with lighting plans it is convenient to make the co-ordinate scales the same. In constructing the chart it adds considerable to its convenience to reduce the vertical dimension by a reduced scale for D, and also adds to its accuracy by bringing the various elements closer together.

The candle-power web was given an elliptical shape for the same reasons.

If the source is not symmetrical about a perpendicular to the reference plane, the tangent scales and elliptical guide lines are used together as above, although the illumination along the non-radial line is not deirved from that along a parallel radial line. In this case the equations are different, while for a symmetrical position of the source they are the same. Thus, in cases 1 and 2, where the axis of the source coincides with the perpendicular to the reference plane, the equations for horizontal illumination are the same. In all other cases the equations differ, usually by a constant in which the angle *d* appears.

From a single horizontal, or normal illumination curve along a radial line, derived from equations 1-1 and 1-3, case 1, any

number of illumination curves along non-radial lines may be derived directly.

FOOT-CANDLE SCALE FACTOR.

When the value of K in the illumination equation is not unity there are at least three ways of proceeding. Thus, if the equation is

$$E = \frac{0.8\ I_e}{H^2} \cos^3 e,$$

then we may multiply the candle-power values by 0.8 and get the illumination data from the corrected photometric curve, or we may use the original photometric curve and multiply the resultant illumination by 0.8, or finally we may use the original photometric curve and change the foot-candle scale by the factor $\frac{1}{0.8}$. The latter method is perhaps the simplest and least liable to error. A scale for changing the foot-candle web is found at the bottom of the chart. The method of using it is given in fig. 11. The value of K in this case is 0.866 (= cos 30). Selecting any point on the foot-candle scale, such as E = 3.0, a line is drawn horizontally to the point *a*. A perpendicular is drawn from K, locating the point O on the base line beneath the standard curves. Another perpendicular is erected from *c* (0.866 = 86.6 per cent.). Drawing a straight line through O and *a* to an intersection with the last perpendicular gives the point *b*, which is 3.0 foot-candles on the corrected web.

RULES.

Each rule given in the following tabulation is divided into three parts.

1. The method of plotting the photometric curve. The location of the zero and 10° points of the photometric curve are given.

2. The point on the candle-power web on which the vertical edge of the triangle is held.

3. The path followed from the edge of the candle-power web. In every case the path starts downward from the edge of the web to the standard curve. The starting point is given. From the standard curve the path is between the guides to the vertical edge of the triangle.

Rule	$f(e)$	Curve Plot I_0, I_{10} on the web at	Triangle Place edge of triangle on following angle on web	Path Point on edge of web to standard curve to triangle
1	$\cos^3 e$	0°, 10°, —	0°, 10°, —	0°, 10°, —
2	$\cos^2 e$	[1]	[2]	0°, 10°, —
3	$\cos^2 e$	0°, 10°, —	0°, 10°, —	[3]
4	$\cos^2 e \cos (e \pm b)$	$b°$, $(10 \pm b)°$, —	$b°$, $(10 - b)°$, —	0°, 10°, —
5	$\cos^2 e \sin e$	90°, 80°, —	90°, 80°, —	0°, 10°, —
6	$\cos^3 (e - s)$	s, $(10 - s)°$, —	0°, 10° —	0°, 10°, —
7	$\cos^2 (e \pm s)$	[4]	[4]	0°, 10°, —
8	$\cos^2 (e \pm s) \sin (e \pm s)$	$(90 - s)°$, $(80 \mp s)°$, —	90°, 80°, —	0°, 10°, —
9	$\cos^2 (e \pm s) \cos (e \pm s \pm b)$	$(\pm s \pm b)°$, $(10 - s \pm b)°$,	$-s \pm b°$, $(10 - s - b)°$, —	0°, 10°, —
10	$\sin^3 e$	90°, 80°, —	0°, 10°, —	s, $10 \pm s°$, —
11	$\sin^2 e$	[5]	[5]	[5]
12	$\sin^2 e \sin (e - b)$	$(90 - b)°$, $(80 - b)°$, —	$b°$, $(10 \mp b)°$, —	0°, 10°, —
13	$\sin^2 e \cos e$	0°, 10°, —	90°, 80°, —	0°, 10°, —

RESULTS OBTAINED IN PRACTISE.

Eight months' experience in the use of this graphic method of obtaining illumination curves has revealed the following points.

1. It is as easy to teach a new man the graphic method as the tabular or point-by-point method.

2. The eye strain involved is but little more than in slide rule calculations, especially if a high accuracy is insisted upon in the latter case.

3. The results obtained, although more liable to small errors, are freer from the large errors that often occur in slide rule work.

4. The time for obtaining a set of three or four illumination curves has been reduced to half or less. This time includes all operations from request to finished tracing.

[1] Lay off photometric values on horizontal edge of web, and mark each point with its angle.

[2] Place edge of triangle through points as laid off on horizontal edge of web.

[3] From 10° on web to standard curve, along guides to left edge of standard curve web, then horizontally to perpendicular under 10°, then follow guides to edge of triangle.

[4] Change angles on photometric curve by $\pm b$ degrees and then apply rule 2, or rule 3.

[5] Change angles on photometric curve to complementary angles, and then, using these new angles, apply rule 2, or rule 3.

In fig. 13. is shown the average errors found in checking a certain set of fifteen curves. The per cent. error is seen to be larger when the illumination curve drops down near the base

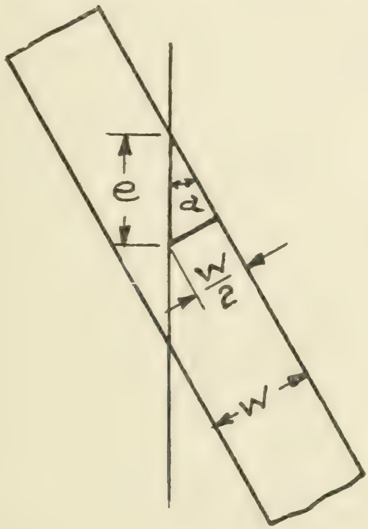


Fig. 12.

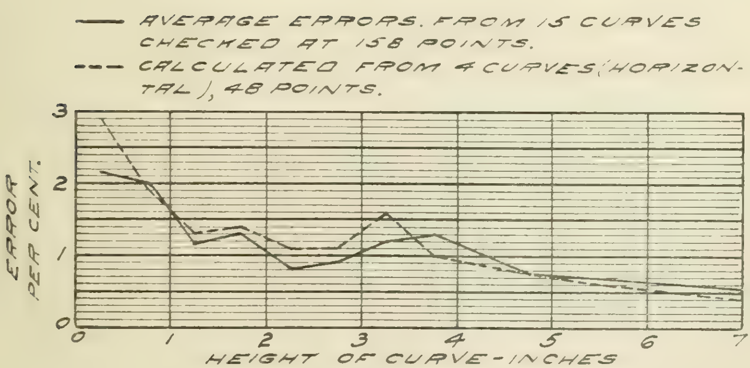


Fig. 13.

line. The average error is 1.25 per cent. These curves were for both horizontal and normal illumination.

In the same figure is shown a dotted curve which was calculated under the following assumption:—

1. The average width of an illumination curve as traced for blue-printing, is 0.02 in. (0.05 mm.).

2. The web is drawn correctly so that any error is due solely to the illumination curve.

In fig. 12 is shown an enlarged section of an illumination curve with a vertical web line crossing it. The width of the curve is W, and the intersection of its center with the web line is the true illumination value. The intersection of the curve and line may be read $\frac{W}{2}$ sec a too high or too low, and still be within the edges of the curve. Let the height of the curve be h, then the possible error in reading at this point is $\frac{\sec a}{h}$ per cent. This formula was applied to the curves shown in fig. 5, with the results given in fig. 13. It is thus seen that the error in practice averages almost exactly half the vertical width of a line 0.02 in. (0.05 mm.) wide.

DISCUSSION.

MR. G. H. STICKNEY: The photometric curves apparently provide for only one hemisphere. How are flux calculations involving both the upper and lower hemispheres handled?

I notice that zero degrees seems to be used to indicate the horizontal. I was under the impression that the Schenectady laboratory of the General Electric Company is using the vertical as the origin, as are most other laboratories, and I would like to ask if they are changing this practise?

MR. FRANK A. BENFORD, JR.: In reply to Mr. Stickney's question regarding light from the upper hemisphere: the illumination in the upper hemisphere is found by plotting the distribution curve for the upper hemisphere.

About the angle: zero is used on the axis of the lamp; but in constructing this chart it was found necessary to place the axis of the distribution curve on the horizontal edge of the web marked 0 degrees.

REPORT OF THE COMMITTEE ON NOMENCLATURE AND STANDARDS.*

I. INTERNATIONAL RELATIONS.

In accordance with the instructions of the Baltimore convention, the committee continued during the year past to endeavor to come to an agreement with foreign bodies on the question of nomenclature, symbols, and definitions.

Our colleague, M. Blondel, placed the set of definitions and symbols, as adopted tentatively by this committee and reported at the Baltimore convention,[1] before the International Photometric Commission at the meeting of that commission in Zurich in July, 1912. That commission referred the consideration of these proposals to a sub-committee composed of the representatives of the national laboratories, namely, Mr. C. C. Paterson of the National Physical Laboratory, England, who is also a member of this committee; M. Laporte of the Laboratoire Central d'Electricité, Paris; Dr. Brodhun of the Physikalisch-Technische Reichsanstalt, Berlin; Dr. Kusminsky of Vienna, and Dr. Hyde of Cleveland, also a member of this committee.

It is important also to notice that the International Electrotechnical Commission, assembled in Turin in September of last year, passed a resolution to the effect of recommending that the national committees of that commission should, in matters concerning illumination and its nomenclature, co-operate with national societies having to do especially with such matters. This committee was represented at that meeting by two members of the United States National Committee of the International Electrotechnical Commission delegation. Acting further in accord with instructions of the society, the committee sent to a large number of technical and scientific societies in this and other countries a circular letter proposing an international conference. This letter read as follows:

* A report presented at the sixth annual convention of the Illuminating Engineering Society, Niagara Falls, Ont., September 16-19, 1912.

[1] TRANS. I. E. S., vol. v, p. 603, (1910).

The Illuminating Engineering Society, acting upon a report of the committee on nomenclature and standards, which was presented at Chicago, September 25, 1911, at the annual convention of the society, adopted the following resolution.

Resolved. That the committee on nomenclature and standards be instructed to communicate with bodies throughout the world interested in photometry and illumination, with a view to arranging an international conference to consider the definition of terms employed in illuminating engineering, their nomenclature and notation.

Since the formation of this committee of the society in 1907, numerous proposals have been placed before it in relation to definitions, nomenclature and notation, many of which appear properly to call for international action ; and the society has felt that it would be undesirable to adopt definitely any proposition that might not meet with international approval.

It is believed that such a conference as that proposed would harmonize any different views that may exist, and would result in a truly international system of terminology in photometry and illuminating engineering.

It is suggested that, in advance of the meeting a preliminary organization be effected, including a representative of each of the bodies adhering, to formulate the proposals to be brought forward at the conference. It is further suggested that the conference be held at the Hague in the autumn of 1912.

In accordance with the above mentioned resolution, we beg to ask your views as to the desirability of holding such an international conference, together with your suggestions as to its scope, form of organization, and the time and place of meeting.

The proposal in the letter was in general favorably received, although on the part of some societies the objection was made that it would be advisable to endeavor to use the organization which has already been in existence for a number of years, under the name of the International Photometric Commission, rather than to attempt to organize an entirely new body to consider these matters. It was pointed out that certain action had been taken by the International Photometric Commission, which, at present, is an organization of the gas lighting interests alone, to widen the scope of that commission by inviting the co-operation of representatives of the national committees of the International Electrotechnical Commission.

While, therefore, it would have been perfectly feasible for this society to have issued a definite call for the proposed conference with the assurance of sufficient international support to make the conference a success, yet it was deemed advisable to

hold the matter in abeyance for the present, awaiting the outcome of the action of the International Photometric Commission.

Accordingly a letter was issued in April, 1912, to the societies which had been first addressed in the matter, as follows:

Referring to the letter of this committee proposing an international conference on photometric units, I beg to inform you that the committee has, as a result of a study of the situation, passed the following resolution:

WHEREAS: A communication has been received from the chairman of the American delegation to the International Photometric Commission (Zurich) to the effect that that commission intends to extend its membership in order to make it representative of all photometric interests, be it resolved that the proposition of this society to hold an international conference on the units and terminology of illuminating engineering be deferred for this year and until it can be ascertained whether the action aimed at can be secured through the International Photometric Commission.

In the meantime, the committee had been in touch with the authorities of the American Gas Institute, and had found that the program of enlarging the International Photometric Commission, as proposed at its 1912 meeting, was not acceptable to the American Gas Institute; since the latter body favored a much more radical reorganization of the International Photometric Commission, one which would make this body fully representative of all lighting interests on equal terms. Such a reorganization would, in the opinion of this committee, render the International Photometric Commission an entirely suitable body to take up the questions which it had proposed should go to a special conference. The committee was in touch with the United States National Committee of the International Electrotechnical Commission, through its president, Mr. C. O. Mailloux, on this matter and was working in harmony with it.

In April, Mr. Mailloux went abroad to attend to certain matters of the International Electrotechnical Commission and kindly undertook to express to those interested the views of this committee on the question in hand. The committee desires to express its great appreciation of the hearty co-operation of Mr. Mailloux and of the valuable assistance which he has rendered. In May, Dr. Hyde, of this committee, also went abroad as a representative both of the American Gas Institute and of this committee, with the purpose of furthering the proposition in

regard to the reorganization of the International Photometric Commission proposed by the American Gas Institute.

As a result very largely of Dr. Hyde's very efficient work, the president of the International Photometric Commission, M. Vautier, has made a formal proposal to the constituent societies, to enlarge the International Photometric Commission, in such a way as to render it representative of all the important photometric interests in a manner satisfactory to them, so that there should be only one recognized international body charged with the establishment of photometric nomenclature and standards, and with the solution of all questions concerning photometry. He has further appointed the existing sub-committee, to which the matter of our proposed definitions was referred, and which is named above, as a special sub-committee to consider the proper method of reorganizing the photometric commission, and to submit a suitable plan to the constituent societies of that commission. Of this sub-committee, Mr. C. C. Paterson has been named secretary. Your committee, therefore, confidently hopes and expects that the international action, which it desires, will be undertaken eventually by the international body so constituted and that the end which it has sought will, therefore, be completely attained and in an eminently satisfactory manner.

In the meantime, this committee has endeavored to formulate its views on some important terms and definitions, with the hope of aiding eventually the proposed international convention.

II. PROPOSED DEFINITIONS.

Your committee has held many meetings during the past year for the consideration of definitions of photometric quantities and begs to submit the following list tentatively adopted:

Luminous flux is radiant power evaluated according to its capacity to produce the sensation of light.

The stimulus coefficient K_λ for radiation of a particular wave-length is the ratio of the luminous flux to the radiant power producing it.

The mean value of the stimulus coefficient, K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

The luminous intensity of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

Let I be the intensity, F the flux and ω the solid angle.

Then $$I = \frac{dF}{d\omega}$$ or, if the intensity is uniform,

$$I = \frac{F}{\omega},$$

Illumination, on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area.

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then $$E = \frac{dF}{dS},$$ or, when uniform,

$$E = \frac{F}{S},$$

Candle,—the unit of luminous intensity maintained by the National Laboratories of France, Great Britain, and the United States.[2]

Candle-power,—luminous intensity expressed in candles.

Lumen,—the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of one candle-power.[3]

Lux,—a unit of illumination equal to one lumen per square meter. The C. G. S. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One millilumen per square centimeter (milliphot) is a practical derivative of the C. G. S. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots.

Exposure,—the product of an illumination by the time. Blondel has proposed the name "phot-second" for the unit of exposure in the C. G. S. system.

Brightness, b, of an element of a luminous surface from a given position, is the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per square centimeter of the projected area.

Defining equation:

Let θ be the angle between the normal to the surface and the line of sight.

Then
$$b = \frac{dI}{dS \cos \theta}$$

Normal brightness, b_0, of an element of a surface (sometimes called *specific luminous intensity*) is the ratio of the luminous intensity of the element taken normally to the surface of the element, and is expressed in candles per square centimeter.[4]

[2] This unit, which is used also by many other countries, is frequently referred to as the international candle.

[3] A uniform source of one candle emits 4π lumens.

[4] In practise, the brightness b of a luminous surface or element thereof is observed, and not the normal brightness b_0. For surfaces for which the cosine law of emission holds, the quantities b and b_0 are equal.

Defining equation:

$$b_0 = \frac{dI}{dS}, \text{ or, when uniform,}$$

$$b_0 = \frac{I}{S}.$$

Specific luminous radiation.—the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per square centimeter.

Defining equation:

Let E′ be the specific luminous radiation.

Then, for surfaces obeying the cosine law of emission,

$$E' = \pi b_0.$$

Coefficient of reflection.—the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection the flux is reflected from the surface in all directions in accordance with Lambert's cosine law. In most practical cases there is a superposition of regular and diffuse reflection.

Coefficient of regular reflection is the ratio of the luminous flux reflected regularly to the total incident flux.

Coefficient of diffuse reflection is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}$$

Primary luminous standard.—a recognized standard luminous source reproducible from specifications.

Representative luminous standard.—a standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

Reference standard,—a standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.[5]

Working standard,—any standardized luminous source for daily use in photometry.

Comparison lamp,—a lamp of constant but not necessarily known candle-power against which a working standard and test lamps are successively compared in a photometer.

Test lamp, in a photometer,—a lamp to be tested.

Performance curve,—a curve representing the behavior of a lamp in any particular (candle-power, consumption, etc.) at different periods during its life.

Characteristic curve,—a curve expressing a relation between two variable properties of a luminous source, as candle-power and volts, candle-power and rate of fuel consumption,[6] etc.

Mean horizontal candle-power of a lamp,—the average candle-power in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

Mean spherical candle-power of a lamp,—the average candle-power of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

Mean hemispherical candle-power of a lamp (upper or lower),—the average candle-power of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

[5] It is desirable that the representative luminous standard should be a primary luminous standard as above defined, but if the precision with which the primary standard can be reproduced is insufficient, the representative standard may have to be constituted in some other manner, as, for example, by a group of seasoned incandescent electric lamps in which the mean value of the group, originally derived from some primary standard, is assumed to remain constant, and is used to maintain the value of the unit. Thus, the Hefner lamp is in Germany both the primary and the representative standard, whereas in America it is a primary standard, but not the representative standard. In the United States, the representative standard is a group of seasoned incandescent lamps at the Bureau of Standards in Washington. This is the most authoritative source for the calibration of reference standards in the United States.

[6] Curves expressing the behavior with respect to time of life are her excluded, being considered as performance curves.

Mean zonal candle-power of a lamp,—the average candle-power of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone divided by the solid angle of the zone.

Spherical reduction factor of a lamp,—the ratio of the mean spherical to the mean horizontal candle-power of the lamp.[7]

TABLE I.

Photometric magnitude	Name of unit	Symbols and equations of definitions
1. Luminons flux	Lumen	F. Ψ
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega}$ $\Gamma = \frac{d\Psi}{d\omega}$
3. Illumination	Phot., foot-candle, lux	$E = \frac{dF}{dS} = \frac{I}{r^2} \cos\theta.$ β
4. Exposure	Phot-second	Et
5. Brightness	Apparent candles per sq. cm. Apparent candles per sq. in.	$b = \frac{dI}{dS \cos\theta}$
6. Normal brightness	Candles per sq. cm. Candles per sq. in.	$b_0 \quad \frac{dI}{dS}$
7. Specific luminous radiation	Lumens per sq. cm. Lumens per sq. in.	$E' \quad \pi b_0$
8. Coefficient of reflection	—	$m = \frac{E'}{E}$

SYMBOLS.

In view of the fact that the symbols heretofore proposed by this committee conflict in some cases with symbols adopted for electric units by the International Electrotechnical Commission, it is proposed that where the possibility of any confusion exists in the use of electrical and photometrical symbols, an alternative system of symbols for photometrical quantities should be employed. These should be derived exclusively from the Greek alphabet, for instance:

Luminous intensity.......................... Γ
Luminous flux.............................. Ψ
Illumination .... B

[7] In the case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.